Embedded Networks:

Pervasive, Low-Power, Wireless Connectivity

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Departmental Committee on Graduate Students Program in Media Arts and Sciences Abstract

The lack of effective networking technologies for embedded microcontrollers is

inhibiting the emergence of smart objects and "Things That Think."

A practical communication infrastructure for Things That Think will require wire-

less network connections built directly into microcontroller chips. After showing

that digital processing, application languages, and wireless links are not the bottle-

neck, this thesis turns its attention to network designs. It presents architectures and

algorithms that implement self-organizing networks, requiring minimal pre-plan-

ning and maintenance.

The result is a radically new model for networks—embedded networks—designed

specifically to interconnect untethered embedded microcontrollers. The thesis cul-

minates in the design, implementation and evaluation of a hardware system that

tests and validates the approach.

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CHAPTER 1 A Network on Every Chip

A trillion dumb chips connected into a hive mind is the hardware. The software that runs through it is the Network Economy. A planet of hyperlinked chips emits a ceaseless flow of small messages, cascading into the most nimble waves of sensibility. Every farm moisture sensor shoots up data, every weather satellite beams down digitized images, every cash register spits out bit streams, every hospital monitor trickles out numbers, every Web site tallies attention, every vehicle transmits its location code; all of this is sent swirling into the web. That tide of signals is the net.

—Kevin Kelly "New Rules for the New Economy" [Kelly 1997]

An unfulfilled promise

For years, visionaries have predicted that tiny computers will soon be woven into the everyday fabric of our lives and a world densely populated with "smart objects," giving rise to "Ubiquitous Computing," [Weiser 1991], "The Network Economy" [Kelly 1997], and "Things That Think" [Gershenfeld 1999]. These predictions have not yet been realized. Why not?

Processing power has become cheap and plentiful. Dollar for dollar, microcontrollers are a thousand times faster than a decade ago [Moravec 1998]. In the year 2000 alone, the total production of microcontrollers exceeded the world population [Tennenhouse 2000]. These tiny chips are being embedded into everyday objects—watches, pacemakers, smart cards, traffic lights, children's toys—at a prodigious rate. Clearly, available processing power is not the limiting factor.

Languages for microcontrollers have also proliferated. Mobile agents [Minar 1999], "thin clients" [emWare 2000], JINI [Sun 2000] and dozens of other computationally lightweight languages have been developed to support dedicated applica-

tions in embedded devices. Availability of these languages has not resulted in the predicted explosion of smart objects.

The steadily falling price of microcontrollers has resulted in situations where the cost of a single connector can exceed the cost of the microcontroller it connects¹. In the last few years, industry standards such as IrDA [IrDA 1998], IEEE 802.11 [IEEE 1999], and Bluetooth [Bluetooth 1999] have created wireless interconnect systems that are less expensive than their wired counterparts. Since these wireless technologies themselves make heavy use of semiconductor technologies, they enjoy progressively lower cost and increased communication rates per unit power.

Despite the availability of these essential ingredients—cheap, abundant processing; lithe application languages; and inexpensive wireless links—few everyday objects show any signs of increased intelligence.

Networking: the missing link

A typical embedded microcontroller works in relative isolation, unable to draw upon information or exert any influence beyond its immediate realm. For all its computing power, it is like a genius sequestered in a basement: smart and capable, but having neither sensory inputs to give it context nor the means to express what it knows. We are left with ubiquitous but senseless computing and billions of Things That Think which cannot relate.

Legacy networks are ill-suited for linking embedded microcontrollers Talk is cheap, at least among humans. But for the tiny embedded microcontrollers found in common objects, the cost of discourse remains relatively high. Today's digital networks were originally designed to interconnect mainframe and minicomputers and have been adapted, somewhat awkwardly, to connect PCs and lap-

A spot check of a popular electronics part supplier shows that in quantities of one hundred, the popular DB9 serial connector costs \$3.12, a microcontroller that processes one million instructions per second costs only \$0.94.

top computers. These legacy networks are ill-suited for embedded processors: they cost too much, they consume too much power, and they don't scale well to handle the hundreds and thousands of connections required in a world of Things That Think.

Embedded Networking

The lack of effective networking technologies for embedded microcontrollers is inhibiting the emergence of smart objects. What is required is a new model of networking—embedded networking—designed specifically to interconnect embedded microcontrollers.

A network must attain a critical mass if it is to be useful. As proposed by "Metcalfe's Law," the value of a network rises as the square of the number of devices connected. In a world where the number of embedded microcontrollers is growing exponentially, the only reliable way to arrive at and to maintain critical mass is to put the network connection directly on the chip.

The domain of Embedded Networking

Herb Simon points out that it is useful to consider a technology as "an 'interface'... between an 'inner' environment, the substance and organization of the artifact itself, and an 'outer' environment, the surroundings in which it operates." [Simon 1969]. Embedded Networks are built into embedded processors and provide communication links for specific applications in a relationship portrayed below in Figure 1. These contexts dictate the fundamental design requirements of embedded networks.

Embedded Networking is implemented on microcontrollers (its "inner environment") and interacts with dedicated applications (its "outer environment"). Each environment dictates constraints upon its design.

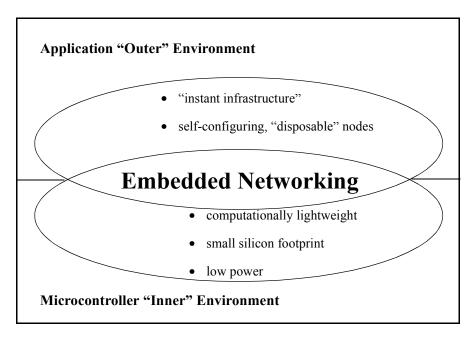


FIGURE 1. Context and constraints of embedded networking

Constraints imposed by the host

An Embedded Network node must not overly tax the microcontroller chip on which it is built. The host microcontroller on which the Embedded Network node is fabricated—its "inner environment"—imposes a set of constraints. The power of microcontrollers lies in their generality: a single microcontroller architecture is suitable for a broad range of applications. For embedded networking to be viable, it too must be adaptable to a broad range of applications. Since the embedded network system resides on the microcontroller chip itself, it must not impose a significant burden on the chip, giving rise to the following design principles:

LOW POWER CONSUMPTION

For an embedded network node to be an attractive candidate for integration onto a microcontroller, it should not exceed the power consumption of the microcontroller itself.

One of the consequences of Moore's Law—the proposition that the number of transistors per unit area of integrated circuit doubles every eighteen months—is that of reduced power. Smaller devices have lower parasitic capacitance, which in turn results in reduced switching currents. Microcontrollers now exceed 10⁹ instructions per second ("1 GIP") per watt, or "one MIP per milliwatt," allowing substantial computation to be powered by relatively small batteries.

Some of the more aggressive radio designs to date have yielded systems that consume approximately 4 nano Joules per transmitted bit [Carvey 1996]. With a continuous transmission at 100 KBits/second, these radios will consume 400 μ Watts—a figure on par with the power consumption of modern host microcontrollers.

SMALL SILICON FOOTPRINT

The manufacturing cost of silicon microcontroller chips is correlated to die size. More smaller chips can be packed onto a single silicon wafer, and smaller chips have higher yields. In order to keep costs low, the circuitry that implements embedded networking should account for a small percentage of the overall chip size. This favors networking algorithms with small routing tables and computational simplicity.

LOW COMPUTATIONAL OVERHEAD

Computing consumes power. Networking algorithms that require less computation will be suitable for wider range of applications, especially those that are limited by available power.

As of this writing, several processor families meet or exceed 1000 MIPs per Watt, including Intel's XScale based StrongARM, Hitachi SDH-4, Texas Instruments MSP430 and Toshiba TX19. The list is growing rapidly.

Constraints imposed by the application

The application—the "outer environment" of Embedded Networking—imposes a second set of design constraints³.

Things That Think will become woven into our everyday environment, standing ready to serve wherever and whenever we want them and fading into the background whenever we don't. The networks linking these devices will create their own invisible mesh of communication without pre-planning, intentional placement or maintenance. If a device demands our attention, it should be due to an application-specific imperative and not due to a failing of the network⁴.

The major design principals for Embedded Networking imposed by its Outer Environment can thus be summarized as follows:

INSTANT INFRASTRUCTURE

It is unreasonable to expect people to configure and administer a network of Things That Think. An Embedded Network must serve its users, not the other way around. This requires a network system that is created upon demand and automatically reconfigures itself as devices are added to or removed from the network.

SELF-CONFIGURING, "DISPOSABLE" NODES

Properly designed Things That Think will have networking built in, not added on, which will be reflected in their usage: devices will become integrated into a network simply by physically bringing then into the networking environment⁵. The

^{3.} In this setting, *application* means "the task to which the system is applied" as opposed to "software written in support of a task."

^{4.} In the terminology of philosopher Martin Heidegger, Embedded Networking should support devices that are "ready to hand" without causing them to become "present at hand."

network should support dynamic discovery and routing so that network services remain available as much as possible, even as devices go off-line or move.

The lifetime of a network connection will be the same as the lifetime of the object into which it is embedded. The day you dispose of an object, you dispose of the network connection without giving it a second thought.

CASUAL PLACEMENT

Conventional wireless networks are carefully planned with respect to location, usage patterns and density. By contrast, the quantity and density of an Embedded Network cannot generally be known beforehand. The design of an Embedded Network should support a broad range of possible device configurations, from the few to the many and from very sparse to very dense.

Contributions of this thesis

GRAD - GRADIENT ROUTING FOR AD HOC NETWORKS

Chapter 4 describes "GRAd," a decentralized, self-organizing, multi-hop network architecture that addresses many of the design issues outlined above. GRAd's routing algorithms offer dynamic discovery and routing, and are shown to be robust even in networks with a high degree of topological change. Its multi-hop approach offers significant savings in radio transmit power. The decentralized approach used by GRAd avoids the congestion of a single base station or access point, allowing it to support up to thousands of nodes. By allowing redundancy among relaying nodes, GRAd exhibits improved reliability over unreliable links. GRAd exploits a simplified Medium Access (MAC) layer to attain lower power per transmitted bit than other comparable networking algorithms. By storing only information about

Some applications may call for "imprinting" a device prior to its use, for example to establish ownership. See [Stajano 1999] for an excellent description of how this can be implemented.

routing endpoints, GRAd's routing tables stay relatively small, and its networking algorithms are computationally simple—both of these points work together to make GRAd ideal for direct implementation on embedded microcontrollers.

DISTRIBUTED SYNCHRONIZATION

While multi-hop routing can significantly reduce the power used for radio transmissions, it doesn't address the power used for reception, which has been shown to dominate the power budget of conventional self-organizing wireless networks [Wheeler 2000]. Chapter 5, "Distributed Synchronization," shows how nodes in a wireless network can synchronize to one another without depending on a centralized time base. Once synchronized, nodes can significantly reduce their power consumption by enabling their radio receivers at selected times.

STATISTICAL MEDIUM ACCESS

Because the placement of nodes in an embedded network are not generally preplanned, the network can experience a wide range of node density. Chapter 6, "Statistical Medium Access," explores the effects of variable density. It will be shown that nodes can use a technique of "statistical medium access," to maximize the likelihood of successful transmission in a crowded environment. The probability of success converges as 1/e for an arbitrary number of co-located nodes.

ARBORNET

Chapter 7 presents "ArborNet," a prototype implementation of an embedded network. Built from commercial off-the-shelf components, ArborNet employs the basic techniques developed by this thesis to implement a self-organizing, wireless sensor network.

The promise, revisited

An Embedded Network is a new paradigm in networking, and offers several benefits over conventional wireless networks.

- Instant Infrastructure—A node in an Embedded Network can join a network simply by bringing it within range of other nodes. This is important for creating "ad hoc" networks quickly on demand, such as in military and emergency applications. Embedded Networks are especially well suited for consumer applications, since new devices can be integrated into a network with minimal effort.
- Proxy Intelligence—A clock should know how to set itself. A child's toy should
 be able to recognize its owner's voice. No particular "intelligence" is required in
 the clock or toy when an Embedded Network links these devices to other computational services.
- Data Aggregation—Today's computers have been described as "deaf and blind" [Pentland 1998], sensorially deprived and unable to act sensibly. Embedded Networks can be used to gather crude data from hundreds or thousands of sources for distillation into high-quality information.
- Cheap Links—In many cases, the cost of physical links is a significant part of a
 total system budget. For example, a light switch costs only about \$2 for the
 switch itself, but the cost of conduit, copper wire, and installation time brings
 the installed cost to over \$70. In many cases, Embedded Network links offer
 inexpensive alternatives to wired connections.

What will happen?

What will happen when every embedded microcontroller comes equipped with its own wireless, self-organizing, scalable network connection? Answering this question is a bit like trying to anticipate the effects of the Internet a decade ago. It was widely believed that the Internet could make a large difference in the way we communicate, but few people could anticipate the depth and breadth of its effects.

So it is with embedded networking. While it may not be possible or practical to anticipate the specific manifestations of embedded networking, it is entirely reasonable to believe that the implications will be large. Some of the applications are easy to imagine:

- ArborNet—understanding the biosphere of the forest floor. A paper company
 owns thousands of acres of forest but, short of sending in survey crews, has little
 knowledge of the ecology and health of the forest. So they create a small "dart"
 with a tiny analysis lab in the tip and a radio link in the tail. Thousands of these
 darts are scattered from an airplane over the forest, forming a complete communication mesh that informs the company about drought, flood, or fire conditions.
- OmniSense—an office building on-line. Once every light switch, thermostat,
 door jamb and motion detector of a building are connected to a network, power
 and security systems can be precisely managed. Over time, the system can learn
 the patterns of usage, allowing it to anticipate ordinary events and to flag abnormal conditions.
- Vox Populi—an inter-village telephone system. Imagine a telephone system that is as easy to set up as handing out telephone handsets. There is no expensive base station—the telephones themselves become the network. And as a boon (or a bane) to the prevailing government, a system can be designed for which centralized control is neither necessary nor possible.
- GridKey—a solution to urban gridlock. Each street corner of a city has a simple sensor that detects the passage of cars. All of the sensors are networked together so analysts—both human and computer—can form a city-wide picture of traffic patterns, adjusting traffic signal timing and issuing advisories to reduce congestion. Individuals can access this information via mobile devices and plan their routes accordingly.

Perhaps the best way to learn about the implications of embedded networking is to build them. Herein lies the crux of this thesis.

CHAPTER 2 Precedents in Wireless Networks

Existing standards do not address the needs of Embedded Networks. In their quest to communicate further and faster, none yield networks that are simultaneously self-organizing, low-power and scalable. In the early 1970s, the Packet Radio Program, funded by the Advanced Research Projects Administration (ARPA), and Norm Abramson's AlohaNet laid the groundwork for wireless digital networks [Kleinrock 1987][Abramson 1985]. Since that time, wireless digital communication systems have grown both in range and capability. Satellite-based systems provide global wireless networks. Locally, high-speed wireless links are commonplace in today's office buildings.

Wireless Local Area Networks (WLANs) offer high speed communication over short distances. The popular 802.11 standard offers communication rates of 11 megabits per second over a range of 200 meters [IEEE 1999]. Wireless Wide Area Networks (WWANs) offer longer range at reduced bit rates, as exemplified by the UMTS standard with a bit rate of two megabits per second carried over cellular telephone networks [UMTS 2000].

BLESSED ARE THE MEEK...

Wireless LAN's are optimized for speed, wireless WAN's are optimized for distance. By contrast, the important attributes for embedded networks are neither speed nor distance, they are power and scalability at a low cost. When voice or image data need to be transmitted, current networks may be the most appropriate. However, for many everyday objects, communication rates on the order of bits per hour—not megabits per second, will suffice. Figure 2 highlights the natural home

of embedded networks: low bit-rate short-haul communications, an area left untouched by conventional wireless networks.

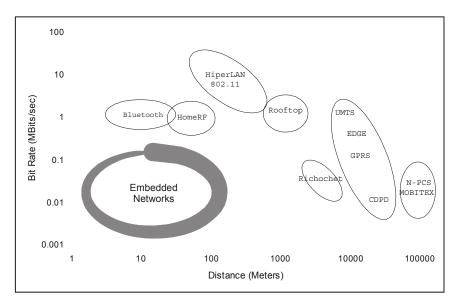


FIGURE 2. Distance versus bit rate for wireless standards

As established in Chapter I, a viable embedded network will have a multi-hop architecture with decentralized control. It will have dynamic routing and will also incorporate power conservation techniques in its core design. As shown in Table 1 below, in their quest to communicate further and faster, none of the existing standards simultaneously address all four of these attributes.

TABLE 1. Packet switched wireless networks

wireless standard	s standard attributes				
	Decentralized	Dynamic Routing	Multi-hop	Managed power	comments
Historical Systems					
AlohaNet	X	X			full flood
Packet Radio	X	X	X		long-haul
Wireless Local Area Networks					
Bluetooth		X		X	Eight nodes per piconet
802.11		X		X	base station mode
802.11 peer-to-peer	X	X			peer to peer mode
Hiperlan/1		X		X	similar to 802.11
Hiperlan/2		X		X	proposed multi-hop option
DECT		X		X	designed for packetized voice
HomeRF		X		X	Hybrid of 802.11 and DECT
Wireless Wide Area Networks					
Metricom Ricochet			Х		fixed "pole top" units
Nokia Rooftop	X	X	X		One Access Point per dozen nodes.
MANET working group	X	X	X		Not a commercial standard (yet)
CDPD, UMTS, EDGE, GPRS		X		X	Cellular Telephony networks
N-PCS, MOBITEX		X		X	Two-way pager networks

Legacy systems

ALOHANET

AlohaNet was developed in the 1970s by Norman Abramson and his colleagues, and is one of the earliest packet-switched wireless digital networks. It used ground-based radios transmitting on a single shared channel. While this architecture is not generally scalable—congestion increases with the number of nodes—AlohaNet and

its analysis spawned many other systems, including Ethernet and TDMA protocols for satellite communication.

PACKET RADIO

Packet Radio systems are among the earlier examples of multi-hop wireless communication systems¹. In 1972, the ARPA launched the Packet Radio Program, designed to develop robust communication systems for the battlefield. In the late 1970s, amateur radio operators developed "Terminal Node Controllers" (TNCs) to form digital links among meshes of ham radios. Since then, TNCs have evolved to support several forms of multi-hop communications, including static and dynamically discovered routing (ROSE and NET/ROM respectively).

Local Area Networks

Всиетоотн

Developed by an industry consortium, Bluetooth specifies a radio and access protocol. The radios are spread-spectrum in the 2.4GHz band, and will form ad-hoc "piconets" of up to eight devices. Within each piconet, one device is the local master and chooses a spreading code. Other devices within that piconet use the master for control and synchronization. One master may participate in multiple picnonets to form a "scatternet," but the specification does not support multi-hop communication.

802.11 WIRELESS LAN

IEEE 802.11 has been widely adopted as an industry standard for Wireless Local Area Networks. Links are specified as 2.4 GHz spread-spectrum transceivers using

To be fair, Packet Radio was hardly the first multi-hop wireless communication network: Napoleon's Optical Telegraph, built before the turn of the 19th century, predated packet radio by 170 years.

CSMA protocols. Channel data rate is as high as 11 MBits/sec. 802.11 works well for linking several dozen devices to a wired Access Point (base station), but will not scale well to higher densities.

802.11 also specifies an ad hoc mode, which provides point to point links at the expense of frame relay and power savings support.

HIPERLAN

Hiperlan/1 (High Performance European Radio Local Area Network) has been developed by ETSI (the European Telecommunications Standards Institute) as a second generation wireless local area network. It supports bit rates of 20 MBits/second at distances of up to 50 meters. The standard specifies the physical layer (PHY) and the Medium Access Layer (MAC), and while it admits the possibility of a multi-hop architecture, it does not specify how it should be implemented.

Hiperlan/2 is a new WLAN standard being developed at ETSI. It specifies channel bit rate of 54 MBit/second with intra-nodes distances up to 100 meters.

DECT

Development of the DECT (Digital Enhanced Cordless Telecommunications) specifications was started in the mid-1980s and finished in 1992 by ETSI. Originally developed as a standard for cordless telephones, the scope of DECT has been expanded to support general digital radio access. The current standard offers a base station architecture with wireless data links of 1.152MBits/second over a range of 100 meters. According to Ericsson, DECT permits the highest user densities of any cellular system, up to 100,000 nodes per square kilometer².

^{2.} See the online document http://www.ericsson.com/BN/dect2.html for more information.

HOMERF

The HomeRF Working Group is creating specifications for low-cost intra-home networking named SWAP (Shared Wireless Access Protocol). SWAP has adopted a hybrid approach, using 802.11 protocols to carry data and DECT protocols to carry voice. A SWAP network will support up to six voice conversations and up to 127 devices in each network.

As in 802.11 networks, a SWAP network can work in ad hoc mode, in which all devices have equal access to the network, and in managed mode, in which one central device coordinates the operations of the other nodes in the network.

Wide Area Networks

RICOCHET

Developed by Metricom Corporation of Los Gatos, CA, the Ricochet Network is one of the first commercial multi-hop wireless digital networks. A mesh of Network Radios, typically mounted on utility poles one to four kilometers apart, relay packets between Wireless Modems and wired Access Points. The first generation of Wireless Modems offered users a channel data rate of 28.8 kilobits per second; newer Modems provide 128 kilobits per second.

A Ricochet network is a multi-hop system, but not self-organizing: adding a new Network Radio to the mesh requires manually incorporating it into the network and setting up static routing to the nearest wired Access Point.

ROOFTOP

Rooftop Communications (recently purchased by Nokia) offers wireless networking products that form a multi-hop, dynamically routed mesh of terrestrial radios. Each radio runs in the 2.5 GHz ISM band, supports link rates of 1.6 MBits/second, and has a range of approximately three miles.

CDPD, UMTS, EDGE, GPRS

CDPD (Cellular Digital Packet Data), UMTS (Universal Mobile Telecommunication Systems), EDGE (Enhanced Data Rates for Global Evolution) and GPRS (General Packet Radio Service) are wireless systems that use cellular telephone networks to carry digital data. Data rates range from 19.2 kilobits per second (CDPD) to a predicted rate of 2 megabits per second (UMTS).

N-PCS, MOBITEX, ARDIS

N-PCS (Narrowband Personal Communication Services), MOBITEX and ARDIS (Advanced Radio Data Information Services) are essentially two-way pager systems. Low bit-rate data is transferred between individual mobile units and high power base stations. Data packets are usually of limited size, and data rates range between 8 and 24 kilobytes per second.

Other multi-hop protocols

MANET

The mobile ad-hoc network (MANET) working group is an effort within the IETF (Internet Engineering Task Force) to develop and evolve routing specifications for wireless ad-hoc networks containing "up to hundreds" of nodes. The working group has already published ten Internet Drafts for discussion and debate, and covers such topics as adaptive routing and quality of service.

A standard benchmark for MANET network protocols assumes that they are implemented using 802.11 wireless links running in point-to-point "ad hoc" mode. In this mode, individual neighbors must be known in order to achieve media access, and the three way handshake at each packet transfer increases latency. Power conservation is not possible as the receiver cannot be turned off.

OTHER PROTOCOLS

The last few years have seen many developments in ad hoc, multi-hop routing protocols. Active areas of research include data-directed routing for network efficiency, data aggregation to reduce network traffic and choosing cluster heads dynamically to reduce per-node power requirements [Intanagonwiwat 2000], [Heinzelman 2000]. These techniques show promise as important components of Embedded Networking systems.

What's missing?

Although existing wireless standards address a range of applications from low bit rate, long distance communication to high-bandwidth, short haul systems, none of them have the right mix of scalability, self-organization and low-power required as a basis for embedded networking. A re-thinking of the network is needed.

CHAPTER 3 Multi-hop Communications

Imagine you are at a party where the conversation flows as freely as the champagne. Suddenly, a guest picks up a bullhorn and shouts out in a booming voice to his friend on the opposite side of the room, asking for some more duck canape. The sound is deafening, and all other conversation comes to an abrupt stop.

The virtues of whispering

Many familiar wireless communication systems, including cellular telephones, two-way pagers and wireless LANs use a *single-hop* design: a central base station or access point maintains direct radio communication with each terminal node of the network. A single-hop system can be likened to that bullhorn: whenever the base station transmits, it precludes other communication within its area.

By contrast, in a *multi-hop* wireless network, each node transmits with reduced power, communicating with a set of neighboring nodes within a limited range. Those neighboring nodes in turn relay the message on behalf of the originator, and so on, until the message arrives at intended destination.

Multi-hop communication conserves transmitter power and increases system bandwidth. Multi-hop networks offer advantages over their single hop counterparts. By reducing the transmit range in each node, multi-hop networks offer substantial power savings. Multi-hop networks exploit spatial reuse, yielding higher effective bandwidth. And by reducing the overall levels of radio interference and noise, multi-hop networks can scale to handle more nodes than single-hop networks.

Single-hop and multi-hop: an idealized comparison

In a single-hop network, each radio transmits with sufficient power to reach its ultimate receiver without intervening relays. In a multi-hop system, each radio transmits with enough power to reach one or more neighboring nodes, which will in turn relay the message until it reaches its final destination.

A representation of single hop communication is shown in Figure 3.

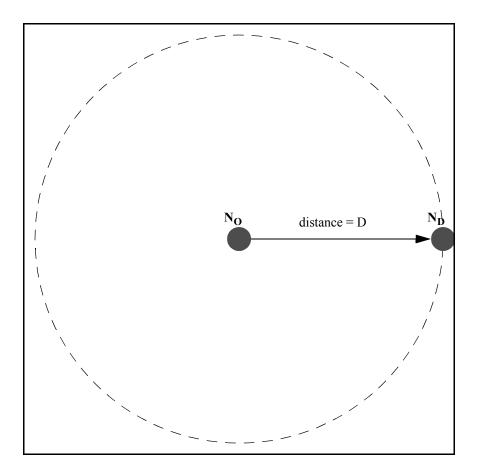


FIGURE 3. Single hop communications

In Figure 3, N_O is the originating node, N_D is the destination node, and the two nodes are separated by a distance D. The transmit power required to span a distance of D is defined to be P.

A multi-hop uses multiple relay stations to get the message from $N_{\rm O}$ to $N_{\rm D}$, as illustrated in Figure 4.

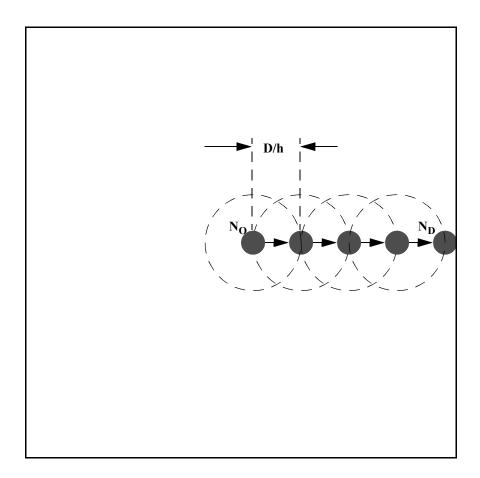


FIGURE 4. Multi-hop communications

Given a system that requires P units of power to transmit its message in a single hop and a path loss exponent of e, the per-node power required to send the message using h hops can be approximated by

$$P_n(h) = Ph^{-e} (EQ 1)$$

The system-wide transmit power is the sum over h hops, or

$$P_t(h) = Ph^{1-e} (EQ 2)$$

The path loss exponent in free space has a theoretical value of 2 for free space, but is typically cited as 4 or higher for office or urban environments.

Assume for the moment that each transmitter covers a perfectly circular area, and the distance covered by a single hop system is D. Assume that the transmitters in an h hop system are equally spaced at distance d = D/h. If each transmitter uses the minimum amount of power to reach the next receiver, the total area covered by the transmitters is given by

$$A_t(h) = \pi d^2 + (h-1)d^2\left(\frac{\pi}{2} - 1\right).$$
 (EQ 3)

If we define $k = \left(\frac{\pi}{2} - 1\right)$, Equation 3 can be written as:

$$A_t(h) = d^2hk + d^2(\pi - k)$$
. (EQ 4)

Substituting D/h for d in equation 4 yields:

$$A_t(h) = D^2 \left(\frac{k}{h} + \frac{(\pi - k)}{h^2}\right).$$
 (EQ 5)

Equation 5 tells us that the area covered by transmitters in a multi-hop system decreases roughly linearly with the number of hops.

Power savings

The rather idealized system using h hops has several advantages compared to its single-hop counterpart. The power required by each node is reduced by h^e , while

the total power consumed by the system is reduced by a factor of $h^{(e-1)}$ and the total area covered by transmission is reduced by a factor slightly larger than h.

As an example, assume a single hop system with a transmit distance of 100 meters in an office environment with a path loss exponent of 4. If we replace the single hop system with a 10 hop system, the transmit power per node is reduced by a factor of 10,000, the total system power is reduced by a factor of 1,000, and the area covered by the transmissions is reduced by approximately a factor of 12.

Figure 5 summarizes the relative transmit power for a variety of hops and path loss exponents.

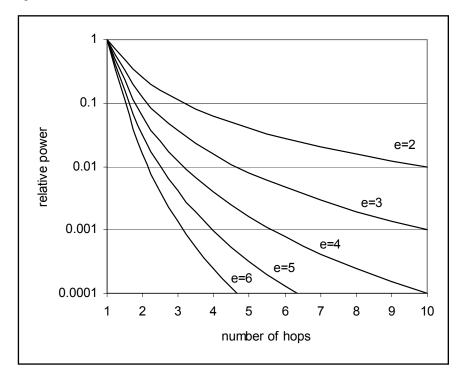


FIGURE 5. Per-node transmitter power (relative to single hop)

The power savings in a multi-hop network can be substantial. For example, in an environment with a path loss exponent of 4, transmitters in a five hop system require 0.0016 of the power compared to a single hop system.

Effects of non-uniform spacing

In the multi-hop scenario given above, relaying nodes are assumed to be evenly spaced between the source and the destination with the transmitter power set to the absolute minimum for reliable communication. In a practical embedded network, nodes will unevenly spaced, and some amount of redundancy and overlap must be expected if there is to be a continuous, reachable path between the originator and destination nodes.

The effect of overlap does not change the per-node transmitter power required, but it does increase the number of nodes involved in relaying the message and thus the total system-wide transmit power. Assuming a factor of N redundancy, the system-wide power of Equation 2 becomes:

$$P_t(h) = PNh^{1-e} (EQ 6)$$

Revisiting the example of a ten hop network with a path loss exponent of 4: if this network has a factor of five redundancy, this represents a factor of 200 reduction in total transmitted system power compared to its single-hop counterpart.

The effect of overlap is to increase the total system-wide power by a linear multiplier, while the savings in power through reduced distance are exponential. The net effect is that a multi-hop system conserves transmit power compared to a singlehop system, even when taking non-idealized spacing of nodes into account.

Summary

Multi-hop systems offer several advantages over single-hop systems.

REDUCED TRANSMITTER POWER

In a multi-hop system, the reduced distances between nodes allows the transmitter power to be reduced exponentially. For example, assuming a path loss exponent of 4, if the 100 meter range of an 802.11 wireless LAN node is reduced to ten meters, its transmitter power may be reduced by 40 db, or a factor of 10,000. This reduction in power results in longer battery life for individual nodes, and reduces the overall amount of clutter in the airwaves.

SPATIAL REUSE

In a single-hop system, transmissions from a base station to a single mobile node blanket the airwaves surrounding the base station. In a multi-hop system, the area covered by transmissions are localized by approximately a factor of h, where h is the number of hops. This permits simultaneous transmissions to take place in physically separate parts of the network—a technique sometimes referred to as *Spatial Division Multiple Access* (SDMA). Since the airwaves can support multiple transmissions, the effective bandwidth of the overall system increases.

MAPPING THE TOPOLOGY

In a single-hop system, a node is either within range of the base station or not: nothing is learned about the topology of the network. In a multi-hop system, the topology of the network can be acquired as the nodes converse with one another. This information can be used to establish optimal routes or physically locate a node. ¹

^{1.} Using a wireless network topology to model physical topography doesn't always work as well as one would hope, as will be shown in Chapter 7.

CHAPTER 4 GRAd: Gradient Routing for Ad Hoc Networks

This chapter presents *Gradient Routing* (GRAd), a novel approach to routing and control in wireless ad hoc networks. A GRAd network attains scalability through a *multi-hop* architecture: nodes that are not within range of one another can communicate by relaying messages through intermediate neighbors. Routing information is established on-demand and is updated opportunistically as messages are passed among nodes.

Unlike other ad hoc routing techniques, a node in a GRAd network does not single out a particular neighboring node to relay its message. Instead, it advertises its "cost" for delivering a message to a destination, and only those neighboring nodes that can deliver the message at a lower cost will participate in relaying the message. In this way, a message descends a loop-free "gradient" from originator to destination.

Since multiple neighbors can participate in the relaying of messages, GRAd maintains good connectivity in the face of frequently changing network topologies. A node does not need to know the identities of its neighbors and establishes routes on demand, making periodic "hello" beacons unnecessary and increasing the overall security of the network. Because GRAd does not use link to link handshakes, end-to-end latencies remain small.

The challenge

In any wireless ad hoc network, a major challenge lies in the design of routing and network control. Lacking any centralized point of control, nodes in an ad hoc network must cooperatively manage routing and medium access functions. Nodes may be mobile, creating continual changes in the network topology. Also, wireless links are not as robust as their wired counterparts; high bit error rates and packet losses are commonplace.

In the last decade, a number of ad hoc network protocols have been proposed. As an indicator of the amount of activity in this field, the Internet Engineering Task Force (IETF) recently formed the Mobile Ad Hoc Networking (MANET) working group to develop ad hoc protocol specifications and introduce them into the Internet Standards track [Macker 2000]. At this time, there are eight separate ad hoc routing protocols under consideration by the working group.

GRAd falls under the category of *on-demand* routing protocols, in which routes are established only when nodes wish to communicate with one another; no attempt is made to maintain state when there is no data to send.

In other on-demand routing protocols such as the *Ad Hoc On-Demand Distance Vector Routing* protocol (AODV) [Perkins 1999] and the *Dynamic Source Routing* protocol (DSR) [Johnson 1999], a node relays a message by sending to a particular neighboring node. The popular 802.11 MAC layer protocol uses "virtual carrier sensing" as part of its collision avoidance mechanism for such unicast transmissions [IEEE 1999], requiring a *request to send / clear to send* handshake (RTS/CTS) between each pair of wireless links. This exchange contributes to significant delays in the relaying of messages, resulting in long latencies.

By comparison, a node in a GRAd network makes no attempt to identify *which* of its neighbors is to relay a packet. Instead, it includes its "cost to destination" information in the packet and broadcasts it. Of all the nodes that receive the broadcast, only those that can deliver the packet at a lower cost will relay the message. In this way, the packet descends a loop-free "gradient" towards the ultimate destination.

Since each transmission is a local broadcast, GRAd does not (and in fact, cannot) use the RTS/CTS handshake associated with unicast transmissions. Consequently, GRAd exhibits very low latencies.

GRAd collects cost information opportunistically: each message carries with it the cost since origination, which is recorded at each node that overhears the transmission, and is incremented when the message is relayed. Thus, the simple act of passing a message quickly and efficiently updates the cost estimates in nearby nodes.

GRAd demonstrates very good immunity to rapidly changing topologies. Since each message reaches a number of neighboring nodes, a single link failure will not cause a break in the communication path as long as another neighbor is available to relay the message.

The GRAd algorithm

ASSUMPTIONS

GRAd is designed for use in multi-hop wireless networks, and makes relatively few assumptions about the underlying physical medium. It does assume that links are *symmetrical*: if Node A can receive messages from Node B, then Node B can receive messages from Node A. In a practical wireless network, strict symmetry is impossible to guarantee due to the mobility of the nodes and time-varying environmental noise. As will be shown in by simulation, GRAd continues to work well in cases where only partial symmetry holds.

GRAd assumes a local broadcast model of connectivity. When a node transmits a message, all neighboring nodes within range simultaneously receive the message.

GRAd provides best effort delivery of messages with the understanding that higherlevel protocols will handle retransmission and reordering of packets as needed. The propagation of a message through the network establishes and updates *reverse path* routing information to the originator of the message. Consequently, GRAd is most efficient when the network traffic has a "call and response" pattern, such as streamed packet data with periodic acknowledgments.

GRAD MESSAGE FORMAT

Messages passed among nodes in a GRAd network carry a header containing the fields shown in Table 2. A description of each field follows.

msg_t	ype o	originator_id	seq_#	target_id	accrued_cost	remaining_value
-------	-------	---------------	-------	-----------	--------------	-----------------

TABLE 2. GRAd message format

 msg_type : Takes on one of two values, $M_REQUEST$ for a reply request message and M DATA for all others.

originator_id: The id of the node originating this message. This id may be statically assigned, or may be dynamically generated on a per-session basis.

seq_#: A sequence number associated with the originator id, and incremented
each time the originator issues a new message. The combination of
[originator_id, sequence_#] uniquely identifies a message, so a receiving
node can distinguish a new message from a copy of a message already received.

target id: The id of the ultimate target for this message.

accrued_cost: Upon origination, the accrued_cost of a message is set to 0.0. When the message is relayed, the relaying node increments this field by one. Thus, accrued_cost represents the estimated number of hops required to return a message to originator id.

remaining_value: Upon origination, this field is initialized to the estimated number of hops to target_id. Whenever the message is relayed, this field is dec-

remented by one. The remaining_value field represents the "time to live" of the message: if it ever reaches zero, the message is dropped.

COST TABLE

Each node maintains a *cost table*, analogous to the routing table of other algorithms¹. The cost table plays two important roles in GRAd. First, the cost table can answer the question "Is this message a copy of a previously received message?" This is determined by comparing the seq_# in the message from a particular originating node against the last seq_# recorded in the cost table for that originator. Second, it can answer the question "What is the estimated cost of sending a message to target node X?" This cost estimate is formed by recording the accrued cost fields for each originator id in received messages.

COST TABLE FORMAT

Each entry in the table holds state information about a remote node, as shown in Table 3.

target_id seq_#	est_cost	expiration
-----------------	----------	------------

TABLE 3. Cost table entry

target_id: The id of a remote node to which this cost entry refers.

seq_#: The highest sequence # received so far in a message from target_id.
When compared against the seq_# of a newly arrived message, this field discriminates between a new message and a copy of a previously received message.

est_cost: The most recent and best estimated cost (number of hops) for delivering a message to target_id.

^{1.} The term "cost table" is chosen over the more conventional "routing table" to emphasize that GRAd does not prescribe a specific route to a target node, but rather it maintains an estimated cost to the target.

expiration: When a cost entry is updated, this field is set to the current time plus cost_entry_timeout. If the current time ever exceeds expiration, the cost entry is purged from the table.

COST TABLE MAINTENANCE

When a message is received at a node, the originator_id of the message is compared against the target_id of each entry in the cost table.

If no matching entry is found, a new cost entry is created, for which target_id is copied from the message's originator_id, seq_# is copied from the seq_# field, and est_cost is copied from the accrued_cost field. The message is marked as "fresh."

If a target_id is found that matches the originator_id of the incoming message, and if seq_# in that entry is lower than the seq_# of the incoming message, the message is marked fresh and the cost entry fields are updated from the corresponding fields in the message.

Otherwise, the message is marked as "stale"—it is a copy of a message previously received. However, if the messages offers a lower cost estimate in its accrued_cost field than the recorded cost in the est_cost field, the lower cost is recorded. This has the effect that if a copy of a previously received message subsequently arrives by means of a shorter path, the shorter path is recorded.

MESSAGE ORIGINATION AND RELAYING

When a node wishes to send a message to a destination for which the cost to the target is known, it transmits a message with the msg_type field set to M_DATA, specifying the destination in the target_id field and the cost to that destination in the remaining value field.

Of the neighboring nodes that receive the message, only those that can relay the message at a lower cost, as indicated by their cost tables, will do so. Before a neigh-

boring node relays a message, it debits the remaining_value field by one. As this process repeats, the message "rolls downhill," following an ever decreasing gradient from the originator to the target.

At the same time, the message carries the originator of the message in the origination_id field and the accumulated relay cost since origination in the accrued_cost field. Upon origination, the accrued_cost is set to 0. Each node that receives the message increments the accrued_cost field of the message and then updates its cost table entry for the originating node based on this information. If and when the message is relayed, it is re-sent using the incremented accrued_cost. By this process, any node that receives a message can update its cost estimate for returning a message to the originating node, whether or not the node is actively involved in relaying the message.

REPLY REQUEST MESSAGES

When a node wishes to send a message to another node for which there is no entry in the cost table, it initiates a "reply request" process. To do so, the originating node transmits a message whose msg_type field is set to M_REQUEST, specifying the destination in the target_id field and initializing the remaining_value field to default_request_cost.

Relaying of the message proceeds much in the same manner as for a M_DATA message, but with one important exception: any node that receives an M_REQUEST message will *always* relay the message the first copy of the message it receives, unless the remaining_value field has reached zero. As with an M_DATA message, the node will increment the accrued_cost and decrement the remaining_value fields of the message before relaying the message.

If a node receives a copy of a previously received message, it will update its cost table entry for the originator of the message if the copy represents a lower cost to the originator, but the node will not relay the copy.

Two important things happen in the reply request process. First, if the destination node is present anywhere in the network (within a radius of default_request_cost hops), it will receive the M_REQUEST message and initiate a reply. Second, each node that receives the M_REQUEST message establishes a cost estimate for returning a message to the originator. Consequently, when the destination node responds to the originating node's request, it can use the more efficient M_DATA message to deliver the reply.

CALL AND RESPONSE

GRAd is uses *on demand* routing: none of the nodes have any *a priori* knowledge of one another. Until a node turns on its transmitter, its presence in the network is not known to other nodes. The general rule for such networks is "if you wish to be spoken to, you must first speak."

The following two figures illustrate the Reply Request process in an ad hoc network, in which Node A initiates a request to Node B, and Node B subsequently responds. It is assumed that initially none of the nodes in the network have any knowledge about nodes A or B.

Figure 6 shows the state of the network after the propagation of a Reply Request message from Node A to Node B. The dashed circle around Node A shows the range of an individual transmitter. Node A starts by transmitting a Reply Request message with an accrued cost of 0 and a target_id set to the ID of Node B. The two neighbors to A each increment the accrued_cost field of the message, record the fact that they are each one hop away from A, and relay the message. This process

continues until all the nodes in the network have received and relayed the Reply Request message.

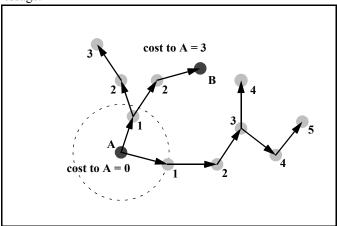


FIGURE 6. Reply Request from node A to node B

By the time A's Reply Request message has arrived at node B, all of the intervening nodes in the network have established a cost estimate for returning a message to A, as shown by the numbers next to each node in Fig. 1.

When Node B receives the Reply Request message from Node A, it responds by originating an "ordinary" message with msg_type set to M_DATA, accrued_cost set to 0, and remaining_cost set to 3, the known cost required to reply to Node A.

Referring to Figure 7, when B transmits this message, the neighboring nodes C and D lie within range and receive the transmission. The cost table of C indicates that A is two hops away, and since the message has an advertised remaining_cost of three, node C should relay the message after decrementing its remaining_cost. Node D, on the other hand, is four hops away from node A, and since it is unable to relay the message at a cost lower than the remaining_cost advertised by the message, it drops the message.

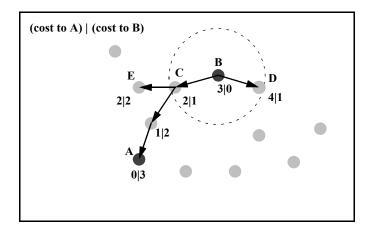


FIGURE 7. Node B replies using the reverse path

As the message is relayed towards A, intermediate nodes also create entries for returning a message to node B. Figure 7 shows the state of the cost tables after the reply has been received at Node A. Next to each node that participated in the reply, the estimated cost for sending a message to node A is shown to the left of the vertical bar, the cost to node B is shown to the right.

In this example, nodes D and E received the message from B, but did not actively participate in relaying it. Nonetheless, by virtue of "overhearing" the message, these nodes have established an estimated cost for sending a message to Node B should the need ever arise.

ROUTE REPAIR

As nodes in the network enter or leave the network, or move relative to one another, the topology of the network can change dynamically, rendering the individual nodes' cost estimates inaccurate.

If the path between originator and target becomes shorter, GRAd will automatically compensate for the change by "skipping over" one or more intervening nodes, and

the revised cost estimates will be reflected in the participating nodes' cost tables after a single call and response pair of messages.

In the event that the path become longer, or intervening nodes change their positions, there is the possibility that the originator's cost estimate no longer has sufficient "potential" to reach the target destination.

GRAd uses end-to-end acknowledgments. If an acknowledgment is not received within a fixed amount of time, the originator can re-send the message, but this time using a higher estimated cost to the destination in the remaining_cost field of the message. This has the effect that more intermediate nodes will participate in relaying the message towards its destination. As before, by the time the message reaches its destination, all of the intermediate nodes will have fresh cost estimates for returning a message to the originator, so the destination node's acknowledgement will be able to follow an updated gradient back to the originator.

If the first attempt to re-send a message with an increased estimated cost fails to reach the destination, the originator can repeat the process, incrementing the initial estimated cost each time.

If, after several attempts, the message fails to reach the destination, the originator can issue a new Reply Request message to create fresh cost estimates from scratch.

IMPLICIT ACKNOWLEDGMENT

To reduce the number of redundant messages transmitted, GRAd uses a variant of passive acknowledgment called *implicit acknowledgment*. A message to be relayed is stored in a MAC-level buffer while it awaits transmission. If a node overhears a neighbor relay a copy of that same message, but at a lower remaining_cost, then the node can assume that the neighbor has succeeded in delivering the message closer to the destination than this node, therefore it can delete the message from the MAC queue and cancel its transmission.

When the ultimate target node receives a message, it re-transmits the message with a remaining_cost set to zero. This has the effect of notifying any neighbors still waiting to relay the message that the target has received the message and that they may abandon their efforts.

Simulation and results of GRAd

Performance of GRAd was simulated using *Jasper* [Poor 2001], an event driven network simulator. The main objectives of the simulation were to characterize the performance of GRAd as a function of transmitted packets and the amount of mobility among the nodes in the network.

SIMULATION ENVIRONMENT

Jasper provides detailed models for components of a multi-hop, mobile, wireless ad hoc network.

The radio modelled by Jasper emulates an FM or spread-spectrum radio, such as would be used in a wireless local area network, operating in an urban or dense office environment. In the absence of other transmissions, a transmitter/receiver pair has a nominal range of 250 meters. Transmit power falls off as the cube of the distance, and a receiver can acquire lock on a transmitter if the signal to interference ratio exceeds 10db. Once locked, a receiver can hold lock as long as the signal to interference ratio exceeds 6db. During reception of a packet, if the signal to interference ratio drops below 6db, the packet is marked as corrupted. The bit rate of the transmitter is 2Mb/sec.

GRAd's MAC layer uses a technique of carrier sense with exponential backoff: when a node wishes to transmit a packet, it first waits for a random interval between T_b and $2T_b$ seconds. At the end of that time, if the carrier sense detects that the local airwaves are in use, it doubles the value of T_b (up to an upper limit) and waits again. If the airwaves are free, it halves the value of T_b (down to a lower

limit) and transmits the packet. If the MAC transmit buffer becomes empty, T_b is reset to its minimum value.

Mobility and traffic models were chosen to emulate those described in [Brooch 1998]. Fifty nodes in a 1500m × 300m arena travel according to the *random way-point* algorithm: each node travels towards randomly chosen locations within the arena at random speeds (evenly distributed between 0 and 20m/sec.). After reaching its destination, the node pauses for a fixed amount of time before setting out for its next randomly chosen location. The *pause time* is varied from 0 seconds for continuous motion to 900 seconds in which case the nodes are stationary for the duration of the simulation.

Traffic is generated by *constant bit rate* (CBR) sources, randomly chosen among the 50 nodes. Each CBR source targets a randomly chosen destination among the remaining 49 nodes. A CBR source generates four 64 byte packets per second. The load on the network is controlled by the changing number of CBR sources. In the tests, 10, 20, 30 and 40 CBR sources were used to generate traffic.

Messages from the CBR source sit in a queue until a route is discovered. To prevent indefinite buffering, messages are dropped if they remain in the queue for over 30 seconds.

Entries in cost tables are set to time out if not updated within four seconds.

In the simulation, a target sends a 32 byte acknowledgment to the CBR source once every two seconds. This acknowledgement message has the dual effect of notifying the CBR source that messages are reaching the target, but more importantly, it refreshes the path from the CBR to the target.

Each test was run for 900 simulated seconds and the results were averaged over ten consecutive runs in order to account for different network topologies.

EVALUATION AND DISCUSSION

Three key performance metrics are evaluated: (i) *Packet Delivery Fraction*—the ratio of data packets successfully delivered to those originated; (ii) the *Average Latency*—the measure of the total end-to-end delay in delivering a packet to a destination; (iii) *Normalized Routing Load*—the ratio of the total number of packets transmitted by any node to the number of packets successfully delivered to the destination.

Figure 8 shows the Packet Delivery Fraction as a function of pause time and for different numbers of CBR sources. As can be seen from the graph, GRAd is insensitive to variable mobility—the percentage of good packets delivered remains essentially constant as the pause time changes.

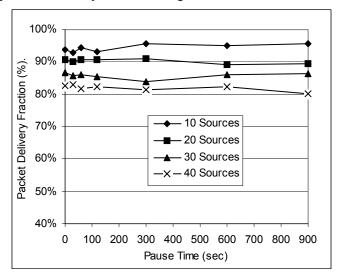


FIGURE 8. Packet delivery fraction

GRAd is robust in the face of changing topology because it enlists multiple neighboring nodes to relay messages from one place to another. If one node moves out of place, other nodes are often available to relay the packet without resorting to rebuilding the route.

Figure 9 shows the average end-to-end latency for successfully delivered packets. In GRAd, latency remains under 7 milliseconds, even under conditions of high mobility and load. By contrast, [Das 2000] reports end-to-end delays of more than 100 milliseconds, and as high as one second for heavily loaded networks. It must be pointed out that is not an exact comparison: in [Das 2000], packet size was 512 bytes and the radio is simulated using a different path loss model.

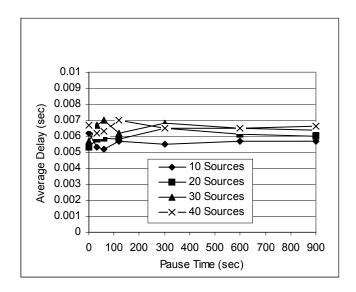


FIGURE 9. Average delay

In any practical implementation, GRAd is still likely to show small latencies since it avoids the RTS/CTS link to link handshake used in other protocols.

However, there is a price to pay for the "fast and loose" routing approach used by GRAd. Fig. 5 shows the routing load for various pause times and CBR sources.

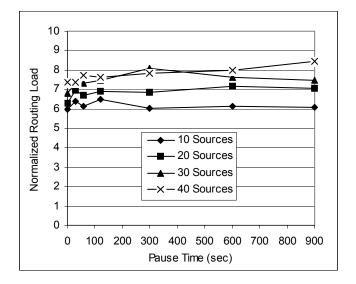


FIGURE 10. Routing load

As Figure 10 shows, for every one data packet received at the ultimate destination, between six and eight packets have been transmitted. Some of these "extra" packets are inevitable, for example, if a path requires two hops from source to destination, this will be recorded as a routing load of two. A destination node always sends an implicit acknowledgment notification, as described in the section on "Implicit Acknowledgment," which contributes to the load. Relatively few of the overhead packets are Reply Request messages, even in scenarios with high mobility². The majority of the overhead packets are due to multiple neighbors attempting to relay the same packet. A consequence of this overhead is that GRAd networks exhibit more congestion than other network algorithms for the same offered load.

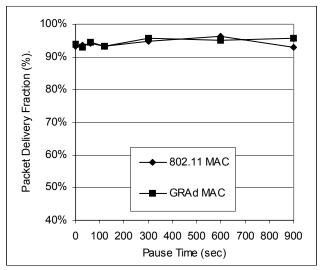
^{2.} In a typical test with 10 sources and 0 second pause time, only 2.5% of all messages transmitted were M REQUEST messages.

CHOICE OF MAC LAYER

In any ad hoc network, there is no centralized control to control access to the airwaves, so nodes depend upon the MAC mechanism to cooperatively share the airwaves. GRAd, in particular, taxes the MAC layer since multiple neighboring nodes will attempt to relay a message soon after receiving it. It was therefore suspected that performance of GRAd would be sensitive to the choice of MAC layer.

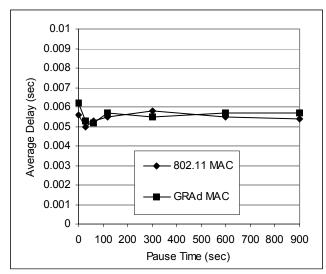
The 802.11 MAC layer [IEEE 1999] is considerably more "fair" than GRAd's simple carrier sense and exponential back off approach described in the section on "Simulation Environment." In the 802.11 approach, the MAC layer implements a countdown timer which is initialized to a random duration proportional to an exponential back off constant. The timer counts down only when the local airwaves are clear. When the timer expires, the MAC layer transmits the packet. This approach distributes air time evenly among neighboring nodes.

The tests were run for 10 CBR sources using the 802.11 MAC layer and compared against the same tests using the GRAd MAC layer—the results are shown in Figure 11. It is interesting to note that there was little effect on the overall performance of GRAd using two substantially different MAC layers.

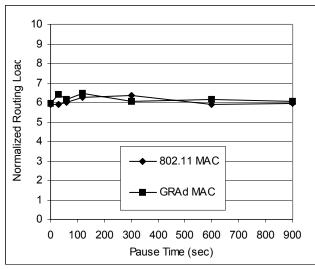


(a) Packet Delivery Fraction (10 Sources)

FIGURE 11. GRAd vs. 802.11 MAC



(b) Average Delay (10 Sources)



(c) Normalized Routing Load (10 Sources)

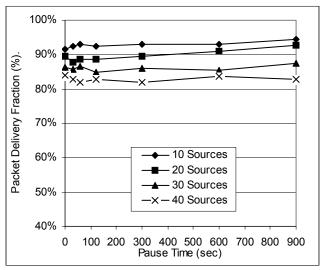
FIGURE 11. GRAd vs. 802.11 MAC

DISABLING ROUTE REPAIR

A previous section describes GRAd's mechanism for Route Repair: if the receiver fails to receive a packet from a sender within the expected period of time, it sends a reply to the sender with an increased remaining cost.

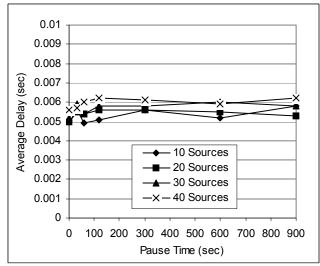
To gain insights to the effectiveness of the route repair mechanism, the tests were run with route repairs disabled: if the network topology changed so an originator no longer reached its destination (more accurately, if an originator stopped receiving packets from its destination), the entries in the cost table would time out and the originator would start a new Reply Request process.

Figure 12 shows the effects of disabling the Route Repair mechanism. The packet delivery fraction drops almost insignificantly, but somewhat surprisingly, the average latency and routing load are both improved.

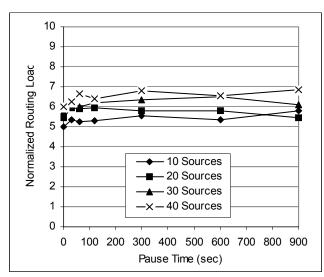


(a) Packet Delivery Fraction

FIGURE 12. Disabling Route Repair



(b) Average Delay



(c) Normalized Routing Load

FIGURE 12. Disabling Route Repair

Proposed extensions to GRAd

The results of GRAd are encouraging, but there are a number unanswered questions whose answers may give insights to the operation of GRAd and suggest areas for improvement.

CONSIDERING MORE THAN NUMBER OF HOPS

Throughout this chapter, the term "cost" has been used to mean "number of hops," but metrics other than the number of hops are possible. For example, a node can charge a higher cost for relaying a message if it notices that its local airwaves are becoming congested, or if its local topology is changing rapidly. The higher relay cost will cause messages to flow around the node if there are other nodes that can relay at a lower cost.

To generalize, in a multi-hop wireless network, the only real choice a node can make is whether or not to relay a message that it has received, and if so, when to relay it. As suggested in [Kramer 1999], it may be useful to structure the problem of routing as a set of software agents residing in the nodes and in the messages; the agents decide what should be relayed and when. The network can then be viewed as a series of *activation* and *inhibition* functions, the former causing a message to be transmitted, the latter preventing it [Intanagonwiwat 2000].

PREFERRED NEIGHBORS

GRAd and AODV share many traits, including on-demand route discovery and updating reverse path information as a message is relayed from one node to next. GRAd permits any neighbor to participate in relaying a message, AODV insists upon a particular neighbor. A compromise between these two approaches shows some promise: A relaying node advertises a cost for relaying a message (a la GRAd) and suggests a preferred neighbor to do the relaying (a la AODV). If that neighbor is not observed to relay the message within a certain amount of time, then non-preferred neighbors may attempt to relay the message. This approach could

reduce some of the routing overhead observed in GRAd while still maintaining robustness in dynamically changing networks.

FUNCTIONAL ADDRESSING

The broadcast nature of GRAd's Reply Request encourages *functional addressing*, in which a node initiates an M_REQUEST message containing a predicate rather than a specifying a fixed target ID. The predicate is a piece of software that embodies a query such as "Are you a color printer?," "Are you a gateway to a wired network?," or "Are you an ARP server?" Each receiving node evaluates the predicate and sends a reply to the requestor if the predicate evaluates to be true. If the requestor receives multiple replies, it can choose the reply that offers the lowest accrued_cost (i.e. is topologically closest) or that best satisfies some other application specific criteria.

PER-SESSION ADDRESSING

In GRAd, routes are created on demand, entries in cost tables are short lived and persist only for the duration of a dialog between two nodes. The identities of the intermediate nodes are not required for passing messages. This opens the possibility of *per-session addressing*, in which an originating and replying nodes choose network IDs at random to be used for the duration of a session.

The space of IDs can be made large enough so the chance of two nodes choosing the same ID is insignificant.

Per-session addressing offers two advantages. The first is security: by changing its advertised address for each session, a node gains some measure of anonymity and protection against malicious eavesdroppers.

Second, manufacturing costs are reduced since network IDs don't need to be assigned and individually burned in at the time of manufacturing.

Summary

GRAd offers a new approach to ad hoc, on-demand routing. Rather than sending unicast packets, it exploits local broadcasting to contact multiple neighboring nodes. Messages descend a cost gradient from originator to destination without needing to identify individual intermediate nodes. Cost functions are updated opportunistically as messages are passed from one node to the next.

Through simulation, the performance of GRAd has been tested and characterized under a variety of load and mobility conditions. The results of the tests show that GRAd exhibits very low end-to-end packet delays and offers good immunity to rapidly changing topologies.

CHAPTER 5 Distributed Synchronization

In a decentralized multi-hop network, it is often desirable to distribute shared information among all the nodes in the network. Since each node can communicate with only a subset of the rest of the network, information must propagate in multiple hops if it is to reach all of the nodes in the network.

Of particular interest are the dynamics of attaining synchronization across a network of nodes. Using today's technology, it is unreasonable to assume that nodes will be fabricated with permanent real-time clocks or will have access to a common wireless time base, such as Global Positioning System (GPS) timing information. Consequently, timing must be agreed upon dynamically.

The algorithm for distributed synchronization is simple: once every T_s seconds¹, node n broadcasts its internal time value, Ψ_n , to its neighbors. Upon receiving a message from a neighbor, a node adjusts its internal time to the average of its previous time and the time advertised in the message.

Given a network of N co-located nodes in which every node can receive the transmissions of all other nodes, it is easy to show that the maximum spread of the shared time will decrease by a factor of two each time a node broadcasts its value, or a factor of 2^N every T_s seconds.

Predicting the rate of convergence for networks that are not co-located is not so simple. The maximum error among the nodes depends on both initial conditions

In practice, the T_s interval will be randomized slightly to reduce the chance of repeated collisions among neighboring nodes.

and the order in which the nodes advertise their times, so a strict analytical approach is difficult. But using statistical models, it is straightforward to determine an upper bound for the rate of convergence.

In modeling the rate of convergence, the single most important parameter is the "diameter" of the network, where the diameter is defined to be the number of hops in the shortest path between the furthest pair of nodes. The worst case for convergence is when the nodes are arranged in a linear array with the node at one end of the array initialized to a maximum value (assumed in these tests to be 1.0) and all other nodes set to 0.0:

$$\Psi_n = \begin{cases} 1, n = 0 \\ 0, n \neq 0 \end{cases}$$
 (EQ 7)

A linear network of diameter 6 is shown in Figure 13, below.

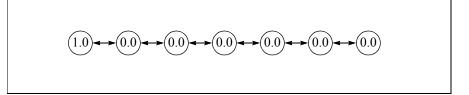


FIGURE 13. Linear network, diameter=6

Running the algorithm

At the beginning of each trial run, a random permutation P(n) on the set of integers 0...N-1 is generated. This determines the order in which nodes broadcast.

In the course of a single iteration, each node broadcasts its internal time value, Ψ_n , to its neighboring nodes, so that the function:

$$\Psi'_{n-1} = (\Psi_n + \Psi_{n-1})/2$$
 (EQ 8)
$$\Psi'_{n+1} = (\Psi_n + \Psi_{n+1})/2$$

is performed N times, once for each n.

In the results shown below, *deviation* is defined as the maximum magnitude difference from the mean of all Ψ_n , and *iterations* is how many iterations were required to bring the deviation below a given threshold.

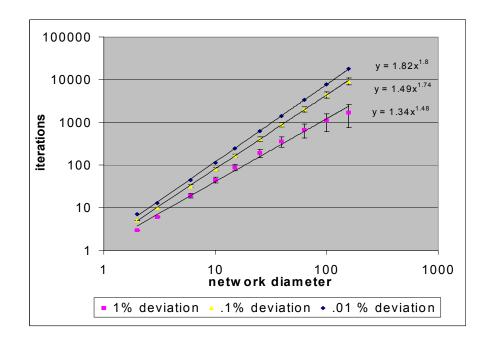


FIGURE 14. Time to converge increases exponentially with network diameter

Figure 14 shows that the number of iterations required to attain a given deviation increases exponentially with the diameter of the network. While theoretically troubling, this is unlikely to be a problem in practice. Both the constant and the exponent are small. To put this in context, a circular network of 1000 nodes and no overlap will have a diameter of 34. If every node in the network runs its algorithm once every second, the system is guaranteed to converge to within 0.01% of maximum deviation within approximately 1,000 seconds, or 17 minutes. For many applications, this is a trivially short amount of time.

Figure 15, below, shows deviation as a function of iterations for a variety of network diameters. It is reassuring to note that the deviation improves exponentially over linear time.

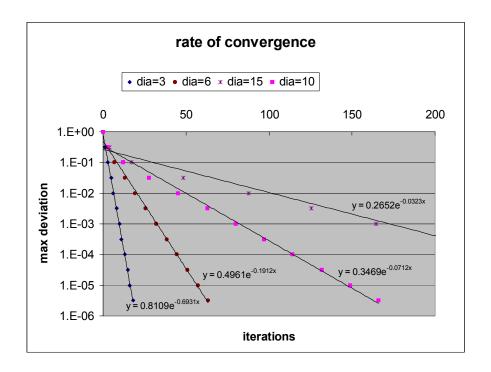


FIGURE 15. Convergence improves exponentially at each iteration

An example: synchronization for spread spectrum

Decentralized synchronization can be used to dynamically establish a common time base among nodes in a network. A common time base can be used to coordinate the hopping sequence in spread spectrum receivers in the network, dramatically reducing the time required to attain synchronization in the receivers. The 802.11 (FH) wireless Local Area Network standard specifies a hop duration of 10 mSec. If the receivers can tolerate a 10% timing error to attain synchronization, it is sufficient to synchronize the nodes within 1 mSec of one another. The hop sequence repeats

once every 660 mSec, so synchronization within 1 part in 660, or 0.15%, is sufficient.

If 100 nodes are arranged evenly in a circular area, the resulting network will have a diameter of approximately 11. By running the simulator (or by extrapolating from the Figure 15 above) it is shown that the system will converge in under 100 iterations. From a cold start, if each node transmits a timing beacon once every second, the system will attain synchronization in under two minutes.

Summary

These results show that a network can cooperatively establish a shared value where each node node periodically broadcasts its time information to its immediate neighbors and takes the average when receiving it. This approach is provably stable, and shows exponential reductions in maximum deviation in linear time for a given network diameter.

It is important to note that the figures given here are for worst-case initial conditions. Several factors can lead to substantial reductions in the time to attain a given deviation. First, perhaps contrary to intuition, mobility among nodes will tend to decrease the time required to attain a given deviation since mobility causes the errors to diffuse more rapidly.

The convergence time can be substantially reduced for nodes entering a pre-existing network simply by having the newcomers "listen but don't talk" for a period of time. This will cause the new nodes to converge rapidly on the values that the incumbent nodes have already agreed upon.

CHAPTER 6 Statistical Medium Access

Channel sharing

If it were necessary for a node to know the identities of its neighbors before communicating with them, how would the node discover their identities? In any network, it is often desirable to provide a communication channel to be shared among all nodes in the network. In a self-organizing network, this channel takes on special significance since it provides a mechanism for a node to share state information with its neighbors without any *a priori* knowledge of their individual identities.

Since this mechanism is used for network control and discovery, we will refer to this channel as the *control channel* through the rest of this section.

There are several ways to implement a shared channel in wireless systems, depending on the link layer communication scheme.

A DEDICATED LINK

A node can be built with two wireless links: one to carry network control information and the other to carry data packets. This approach has several advantages. The control channel link can be implemented as a low power, low bit rate radio. Its receiver can be always on, and the rest of the system lies dormant until a message is received. Additionally, this scheme does not require nodes to be synchronized to one another.

This approach has disadvantages. The cost of the additional radios may be significant. Due to differing propagation characteristics, connectivity among control channel links may be different from connectivity among the data channel links.

A DEDICATED TIME SLOT

Nodes can agree on a common time slot to be used for control information. The primary advantage of this approach is cost and simplicity: no extra radio systems are required.

There is a price to pay for this approach: all nodes must be synchronized to one another. This synchronization requires that nodes are aware of one another, which is at odds with the stated design goal that the control channel is the mechanism used for nodes to discover one another.

A DEDICATED SPREADING CODE

For systems that use spread spectrum communication, a predetermined spreading code can be dedicated to the control channel. This has the advantage that control information can be transmitted at any time with minimal impact on data transmissions.

Using a dedicated spreading code for the control channel requires that the radio receiver in every node has two demodulators—one for the data channel and one for the control channel. This will increase the cost and power consumption of the system. If the radio systems are to attain fast synchronization at the start of each packet, the nodes themselves must be synchronized to one another.

Medium Access and Collision Avoidance

Whether the control channel is implemented as a dedicated radio frequency, time slot or spreading code, it is still a shared resource and subject to contention. If mul-

tiple nodes transmit on the control channel simultaneously, there may be collisions resulting in lost information.

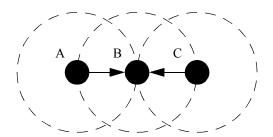


FIGURE 16. Collision

For example, the figure above depicts three nodes. Nodes A and C are within transmit range of node B. If both A and C transmit simultaneously on the control channel, B will not be able to discriminate between the two transmissions and the information will be corrupted, leading to lost data.

A statistical approach

In order for information to be conveyed on a shared channel in a given time slot, exactly one node must transmit. If zero nodes transmit data, no information is conveyed. Similarly, if two or more nodes transmit, there is a collision, and again no information is conveyed.

In statistical channel access, every node that wishes to communicate on a shared channel does so at an agreed upon time slot, but with some probability less than one. The goal is to find the probability that optimizes the chance of successful communication, in particular, that exactly one node transmits data.

Choosing p

If there is one receiving node within range of N potential transmitting nodes, and each transmitting node transmits with probability p, the likelihood of one and only one of the N nodes transmitting is given by:

$$f(p) = p(1-p)^{N-1}$$
 (EQ 9)

When p is set to zero, the transmitters never transmit, so f(0) is zero. When p is set to one, the transmitters always transmit, so if there is more than one neighbor, transmissions always collide. Somewhere in between the two, f(p) rises to a maximum, depending on the number of transmitters in the vicinity of the receiver. The plot below shows the "goodput," or probability of a successful transmission for different number of transmitters as p varies from 0 to 1.

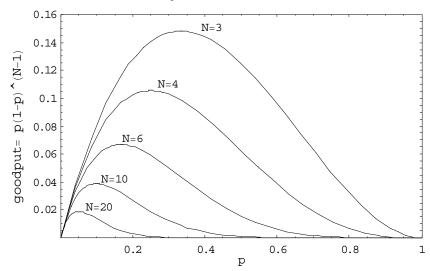


FIGURE 17. Probability of successful transmission

To find the value of p that maximizes the goodput, we take the derivative of (EQ 9) and solve for f'(p) = 0:

$$f'(p) = (1 - Np)(1 - p)^{N-2} = 0$$
 (EQ 10)

By inspection, it is easy to see that there are N-2 zeros when p=1 and one remaining zero when (1-Np)=0, or p=1/N.

This indicates that in order to maximize the goodput, a node that wishes to transmit to a particular receiver should do so with a probability of 1/N, where N is the number of transmitters wishing to transmit and within range of that receiver.

Likelihood of successful transmission

Substituting 1/N for p in equation (EQ 9) gives optimal goodput:

$$f(N) = \frac{(N-1)^{N-1}}{N^N}$$
 (EQ 11)

A plot of goodput versus number of nodes follows. The topmost line is the optimal goodput, attained when p is set to 1/N, where N is the number of transmitters that simultaneously wish to transmit. The two other curves correspond to p=.5(1/N) and p=2(1/N) to show the effect of non-optimal choice of p.

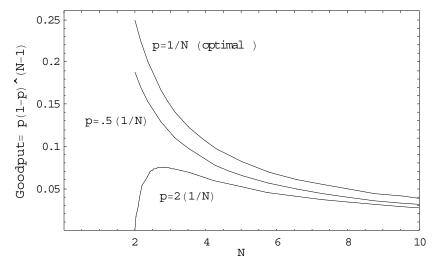


FIGURE 18. Adjusting p as a function of the number of transmitters

This is a function that falls off essentially as K/N, where N is the number of nodes that wish to transmit on the medium and K is 1/E, or 0.367879.

Statistical Medium Access in multi-hop networks

In multi-hop networks, it is often the case that multiple nodes attempt to relay an identical message on behalf of their neighbors. In this case, if N nodes are attempting to deliver the same message, it does not matter which one of the N nodes succeed. To reflect this, (EQ 11) can be multiplied by a factor of N, producing:

$$f(p)N = \frac{(N-1)^{N-1}}{N^{N-1}}, p = \frac{1}{N}$$
 (EQ 12)

As the following plot shows, the probability of successful transmission converges on 1/e (0.367879) as N increases.

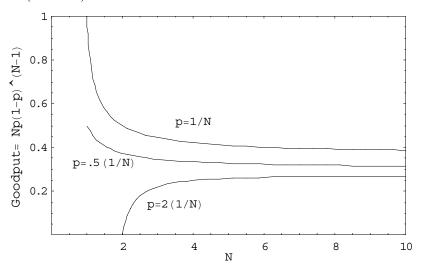


FIGURE 19. Goodput for any of N nodes succeeding

Misjudging N

In general, it is impossible to know exactly the number of neighbors surrounding the intended recipient of a message. What happens to the overall efficiency if sending nodes over- or under-estimate the node density?

To understand the effects of non-optimal choice of p, assume a constant node density—every node has N neighbors—and that every node wants to transmit.

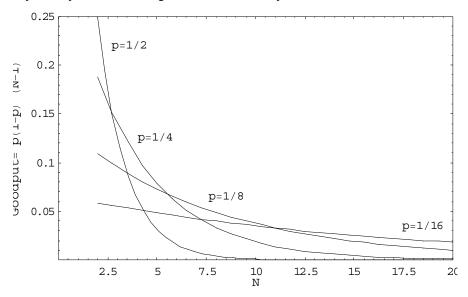


FIGURE 20. Overestimating and underestimating p

Figure 20 shows the likelihood of successful transmission using probabilities of 1/2, 1/4, 1/8, and 1/16. When p is chosen too large (as in underestimating N), the efficiency drops off quickly as the number of nodes increases. When p is chosen too small (as in overestimating N), the efficiency starts out lower than it would for optimal p and tapers off gradually.

Consequently, if the number of neighbors is not known precisely, it is better to overestimate N and choose a value of p smaller than optimal.

Summary

Statistical Media Access can provide a simple and fair mechanism for multiple transmitters to gain access to a shared communication channel in a decentralized network. In a multi-hop wireless network where each transmitter has limited range, Shared Media Access is ideal for broadcasting information to neighboring nodes. Unlike other media access strategies, such as MACA or MACAW, it is not necessary for each transmitting node to know the identities of the receiving nodes in order to initiate a transmission. All that is required for efficient communication is an estimate of how many nearby nodes wish to transmit. When multiple nodes are attempting to convey the same piece of information, worst-case efficiency is 1/E, or 0.367879.

CHAPTER 7 ArborNet: A Proof of Concept

Motivation

Up to this point, this dissertation has moved in the virtual domain, using statistics and simulation to predict the behavior of Embedded Networks. But there are insights to be gained by building physical systems and reducing theory to practice. Thus it was that ArborNet was created.

ArborNet is self-organizing network consisting of twenty-five wireless nodes. Each node is housed in a small weatherproof plastic box, and contains a microcontroller, a digital radio transceiver, three AA sized batteries, a collection of sensors, Light Emitting Diodes (LEDs) and assorted "glue logic." An ArborNet node with its clear plastic cover removed is shown below in Figure 21.



FIGURE 21. One of twenty-five ArborNet nodes

Hardware system

The heart of an ArborNet node is the "Constellation" board, designed by Andy Wheeler with assistance by the author. The Constellation board integrates a versatile 8-bit microcontroller with a short-range radio transceiver, and has proven itself to be a sound platform for network development and testing.

A block diagram of the primary components of the Constellation board is shown below in Figure 22.

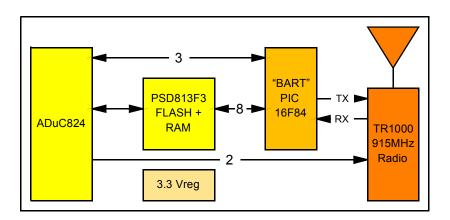


FIGURE 22. Constellation block diagram

PROCESSOR

The Constellation board is built around an Analog Devices ADuC824 microcontroller. The processor is a variant of the mature 8051 family of 8-bit microcontrollers, and contains a set of features that make it especially appealing for Embedded Processing applications.

Power: the ADuC824 is a low-power device for its class. The system uses a 32KHz watch crystal as its primary system clock which is frequency multiplied via a Phase Locked Loop (PLL) to 12MHz, giving a nominal instruction cycle time of 1 microsecond with excellent power management features. The processor draws a nominal

5mA while running, but can be put to sleep, during which time the power consumption drops to approximately 5uA.

Real Time Clock: The ADuC824 has an on-board Real Time Clock (RTC), which measures years, months, days, hours, minutes, seconds with resolution down to 1/128 of a second. When the main processor is put to sleep, the RTC keeps running, so time measurements are unaffected by processor sleep times.

Digital Input/Output: The ADuC824 has a large collection of input/output lines, with support for serial I/O, I2C and ISP devices.

Analog Telemetry: The ADuC has a high-resolution A/D converter with variable gain, multiplexed inputs—a design that made it easy to add sensors to the Constellation board with a minimum of additional circuitry. The ADuC824 also has a pair of 12 bit D/A converters, though they were not used in ArborNet application.

FLASH/RAM EXPANSION

Since the ADuC (and most 8051 based systems) are limited in RAM size, the Constellation includes a PSD813F memory and I/O expansion chip, manufactured by Wafer Scale Integration. The PSD813F adds 128KBytes of FLASH program memory and 2K of general purpose RAM to the system. It includes a JTAG programming port, which greatly speeds up development time during multiple revisions of the firmware.

The PSD813F also provides 32 general I/O ports. Some of these are dedicated to communication with the ADuC824, the remaining lines connect to LEDs and the BART radio interface (q.v.).

RADIO SYSTEM

The Constellation board uses the TR1000 radio transceiver, a single-chip device designed by RF Monolithics. It supports bi-directional digital communications at rates up to 115K Bits/second using an unlicensed ISM frequency band of 915MHz.

The antenna is an integrated patch device made by Lynx technologies. The radio system has been measured to communicate reliably at a range of 30 meters in an open space.

"BART" RADIO INTERFACE

The ArborNet radio communicates at a basic channel rate of 113,630 bits per second, requiring accurate 8.8 uSec timing per bit. To reduce the real-time processing requirements on the system microcontroller, the BART (Block Asynchronous Receive/Transmit) interface serves as an intermediary between the ADuC824 microcontroller and the radio. BART is implemented by a PIC16F84 microcontroller clocked at 20MHz.

To the microcontroller, the BART presents an 8-bit parallel port¹ with a 32 byte internal buffer. For the radio, the BART manages the serial data streams, providing accurate timing on transmit and byte- and bit-level framing on receive².

The BART provides DC balancing of the data: every 8 bits of host data is converted to 12 bits of DC balanced data upon transmission, and converted back to 8 bits upon receipt. The BART also generates and strips synchronization headers at the start of each packet, and doesn't initiate a transfer to the host microcontroller until a valid header is seen. This drastically reduces the amount of time the host microcontroller spends servicing spurious packets.

All higher level processing, including the generation and verification of per-packet CRC codes, is handled by the host microcontroller.

^{1.} The BART's parallel port actually connects to the PSD expansion chip, not to the micro-controller. From a programmer's point of view, the distinction is unimportant.

It is worth noting that the BART chip attains bit level synchronization of the received radio bit stream to within four processor cycles, or 800 nanoseconds, without the addition of special purpose hardware.

POWER SUPPLY

The ArborNet node is powered by three primary AA cells wired in series, which will deliver 4.5 volts when the batteries are new, drooping to under 2.4 volts over time. Since components on the Constellation board require a regulated 3.3 volts, a switching step-up/step-down voltage regulator has been included to provide a constant supply of 3.3V over the life of the batteries.

SENSORS

The Constellation board provides inputs for one high resolution (24 bit) and one medium resolution (16 bit) analog signals. In addition, the ADuC824 has an on-chip temperature sensor, calibrated in degrees Celsius. The Constellation board also connects a battery voltage monitor to one of the analog inputs on the ADuC A/D converter, so each node can monitor and report its own battery status.

Although the Constellation boards have been tested using photo sensors and external temperature sensors, the experiments described here use only the on-chip temperature and battery voltage sensors.

CONNECTORS

The Constellation board has number of connectors for communication and configuration, listed here.

Serial I/O	4 pins for serial input and output. Provides RX, TX, GND, +3.3V				
JTAG Port	14 pins. Used to program the microcontroller and PSD expansion chips.				
PIC programmer	6 pins. Used to program the on-board PIC (BART chip).				
Analog In	6 pins. Provides GND, +3.3V and two analog inputs.				
Jumper block	8 pins. Controls programming of the ADuC824 (_PSEN and _EA), and connects to two general purpose inputs on the ADuC824 for user configuration bits.				
I2C/SPI	6 pins. I2C and SPI high-speed serial interface for small peripheral devices, such as real time clocks, D/A converters, flash RAM.				

TABLE 4. Constellation's I/O Connectors

Software system

One of the design challenges for ArborNet was fitting the software system into an eight-bit microcontroller with limited code and data storage. For the task, a small real-time kernel, "RTX51 Tiny" by Keil Software, was chosen as the basic framework for the ArborNet system.

The bulk of the ArborNet system was implemented in 3300 lines of C code over a period of four months. The development tools from Keil were easy to use. The ArborNet system made extensive use of the RTX51 thread mechanism, which resulted in code that was easy to maintain and understand. Even though the RTX51 kernel offers round robin scheduling, it was disabled in the ArborNet system to simplify the coding and eliminate the risk of race conditions. Given this conservative approach, the RTX51 kernel proved to be robust: no system errors were observed that could be ascribed to the kernel.

The ArborNet packet mechanism

SERVICES, NOT LAYERS

Classic network architectures such as the Open Systems Interconnection (OSI) networking suite defines networking as a set of layers of abstraction, providing well-defined functionality and interfaces at each layer. A layer is designed as a "black box," hiding implementation details and communicating only its immediate superand sub-layers. This approach is designed to simplify the implementation and testing of network systems, but in hiding information at each level from other levels, information that is required at several layers must be replicated, leading to computational and storage inefficiencies.

Embedded Networking algorithms such as GRAd thrive on "hints," and can take advantage of all available information to increase the network efficiency. As an example, it can be useful for the MAC system in a wireless network to keep track of how many distinct neighbors are in the vicinity of the node—the MAC can use this

to predict congestion and adjust its holdoff times accordingly. In a typical layered network model, the MAC is precluded from examining any except the MAC header of received packets, so the network ID of the sending node must be included both in the MAC header as well as in the routing header.

This replication of information results in longer transmitted packets and more storage in the microcontroller. Since conserving power and storate are priorities in the design of Embedded Networking, ArborNet abandons the classic layered model in favor of a "services" oriented design.

LINKING, NOT ENCAPSULATION

In ArborNet, the basic unit of information transfer is a data *packet*—when the radio transmits data, it transmits a single packet. Each packet is implemented as a linked list of *segments*, where each segment carries a segment type and a payload specific to that type. The format of each segment is published and comes with a set of software functions to access the specific fields.

Consequently, any software module in the ArborNet system is allowed to examine an entire received packet for segments that it might find useful. On transmission, a packet is formed quickly and efficiently by pushing segments onto a linked list and is passed around as a single unit—no copying of memory is required as it would be for an model that uses encapsulation.

Software modules may "decorate" a packet, augmenting the information carried by the packet simply by pushing additional segments onto it. As an example, this technique was used to add networking statistics information to packets to ArborNet during system testing and debugging.

PACKET MEMORY MANAGEMENT

The Constellation board has only 2KBytes of RAM memory, which is dominated by packet buffer storage. In this limited environment, the use of linked segments for representing packets made memory management unexpectedly efficient.

The message packet system is initialized with a pool of fixed-size segment structures, all linked into a single freelist. When any software module wishes to allocate a segment, the next available segment is simply removed from the head of the freelist. Each segment is filled in with its segment type, segment size and any appropriate data. When a software module is finished with the segment, it is pushed back onto the freelist.

The size of the fixed-length segment structure is chosen to be long enough to hold the longest segment data. Consequently, many segment types don't fill out the entire segment storage. During radio transmission, the segment is compressed by sending a single byte length field followed by the segment type and only as many bytes of the segment payload as are actually used. Upon reception, the inverse process takes place: compressed segment structures are expanded out into fixed length segments as they are received, the component segments of a packet are linked into a single list and, if the packet is observed to be free of errors, passed to other software modules for processing. After the last software module has processed the packet, the entire packet is returned to the segment freelist.

PACKET SEGMENT TYPES

The ArborNet system implements the following segment types.

SEG_GRAD	Gradient Routing segment. Contains originating node ID, destination node ID, packet sequence number, accrued cost and remaining budget.
SEG_DISCO	Gradient Discovery segment, identical in content to a SEG_GRAD packet, but obeys different rules for relaying.
SEG_COST_L SEG_COST_H	Cost Table segments, containing the contents of the originating node's cost tables. This is split into two segment types, one for the low half of the table and one for the high, because of hardware limitations on the maximum packet size.
SEG_STATS	Node Statistics segment used for debugging and network testing. Contains various statistics, such as the number of packets originated, number of packets received, number of packet relayed.
SEG_TELEM	Telemetry information. Contains the readings of the sensor array on the originating node.
SEG_ARQ	Automatic Retry Request segment. The packet carries with it the retry ID and a number of retries remaining before giving up.
SEG_ACK	Acknowledgement segment, sent in response to a SEG_ARQ. Contains the retry ID of the SEG_ARQ being acknowledged.
SEG_APPX	Request for Application Transmission segment. The packet names a destination node that is requesting regular updates in the form of SEG_COST_L, SEG_COST_H, SEG_TELEM, SEG_STATS and SEG_TIME packets from the receiving node.
SEG_PING	Ping segment. Contains node ID and local system time. Used to advertise presence and synchronization information to neighboring nodes.
SEG_TIME	Time and synchronization status. The packet contains the sending node's current time, the maximum timing error recently seen and the number of SEG_PING packets generated and received.

TABLE 5. Segment types in ArborNet

Data flow in ArborNet

The ArborNet system is implemented using a number of threads and packet queues.

Figure 23 below shows the arrangement: rounded boxes represent processing

thread, bracketed boxes represent packet queues, and lines with arrows trace the flow of packets.

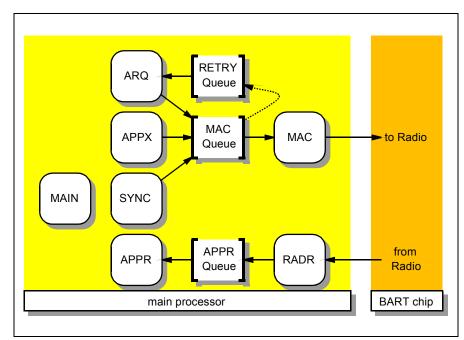


FIGURE 23. Threads and data paths in ArborNet

MAIN THREAD

The Main thread handles the initialization of the system, spawning all the other threads. Once the system is running, it monitors the RS232 serial input line for commands and displays the synchronization status of the real time clock by flashing the on-board yellow LED once every two seconds.

ARQ THREAD

The ARQ thread manages the retransmission of ARQ (automatic reply request) packets. A full description of the ARQ mechanism is described below in "ARQ processing."

SYNC THREAD

The Sync thread generates periodic "ping" packets that broadcast the nodes's Real Time Clock timing information to its immediate neighbors. Upon receiving a ping packet, the system adjusts its Real Time Clock as described in Chapter 5, "Distributed Synchronization." Implementation details of the synchronization mechanism are described below in "Timing services."

APPR THREAD

The Application Receive thread monitors the APPR queue, waiting for packets received by the radio mechanism to come available. When a packet is inserted in the APPR queue, the APPR thread wakes up, removes the packet from the queue, and distributes the packet on a segment-by-segment basis to other software modules. For example, if the incoming packet contains a segment of SEG_TYPE_PING, it passes the packet to the synchronization system for processing.

The APPR thread also prints the contents of each incoming packet in hexadecimal form to the serial output port. This is useful for debugging³, but is designed so any node can be a "gateway node" and log incoming packet data via the serial port.

APPX THREAD

The Application Transmit thread is responsible for sending periodic status reports to a remote node. It waits until it receives a packet containing SEG_TYPE_APPX, that identifies a node wishing to receive status reports and how often those status reports should be sent. It then enters a loop, composing and transmitting cost table

^{3.} The printing of each received packet almost certainly results in some dropped packets:

Due to the non-preemptive scheduling of threads, if a new packet arrives while the system is printing another packet, the 32-byte BART FIFO can overflow, resulting in a truncated packet which will be discarded due to a CRC mismatch.

reports, analog sensor readings, synchronization status, and packet statistic packets to the requesting node.

As written, the APPX thread sends a packet on the average of once every ten seconds.

MAC THREAD

The Medium Access thread monitors the MAC queue for available packets to transmit. When a packet becomes available, the MAC thread delays for a random hold-off interval, using the 802.11-style exponential backoff technique described in the chapter on Gradient Routing. When the holdoff expires, the radio transmitter is set to transmit mode and the packet is passed to the BART radio interface for transmission.

RRCV THREAD

The Radio Receive Thread waits for an interrupt from the BART radio interface, announcing the arrival of a new packet, and proceeds to read bytes from the BART as they become available. Upon reading the end of the packet, the Radio Receive Thread verifies the packet. If the packet is valid, it is stored in the APPR queue and the APPR thread is notified of its arrival.

ARQ processing

ArborNet implements a simple but effective Automatic Repeat Request (ARQ) mechanism. As described in Chapter 5, Gradient Routing works by using reverse path routing information, so sending occasional acknowledgements to an originating node is a natural and useful mechanism for keeping the routing information up to date⁴.

Prior to transmission, an application may augment any packet that contains a GRAd routing segment with an ARQ segment (of type SEG_TYPE_ARQ), containing an

ARQ reference number and a retry count. The packet is subsequently inserted in the MAC queue for normal transmission.

When the MAC module removes a packet from its queue just prior to transmission, the packet is examined. If the packet contains an ARQ segment and the retry count of the segment is non-zero, a copy of the entire packet is installed in the ARQ's Retry Queue. The original packet is transmitted as normal.

Whenever a packet containing an Acknowledgement segment (of SEG_TYPE_ACK) is received, its reference number is compared against that of each ARQ segment of packets waiting in the Retry queue. If the reference number matches, the corresponding packet in the Retry queue is removed and freed—it has been acknowledged and no further retries are required.

Concurrently, the ARQ thread is run whenever a packet is installed in the Retry queue. It sets a time-out counter before attempting retransmission (typically 500 milliseconds). After the time-out expires, the ARQ thread checks to see if there is still a packet available in the Retry queue, since the queued packet may have been acknowledged and removed in the interim. If the packet is still available at the end of the timeout period, its retry count is decremented and its routing header updated before installing it in the MAC queue for subsequent transmission.

When a node receives a packet containing an ARQ segment, it responds by creating a packet with an Acknowledgement segment (of type SEG_TYPE_ACK) with a matching reference number and sending it to the originating node.

^{4.} In the experiments described later in this chapter, the ARQ retry count was set to zero. This means that the recipient would generate ACK replies, but an unreceived ACK never results in retransmission of the original message.

Timing services

ArborNet nodes implement the synchronization mechanism previously described in Chapter 5, "Distributed Synchronization." This section describes the details of the implementation.

In an ArborNet node, local time is represented by an integer indicating 1/128ths of a second and is taken modulus 7680. Consequently, the system has a time resolution of 7.8125 milliseconds and cycles once every minute. These values were chosen based on the resolution of the ADuC824 Real Time Clock hardware and the limits of imposed by representing values in a sixteen bit unsigned integer. As an implementation detail, the current time is formed by reading the Real Time Clock and adding its value to an offset. When adjusting the local time, ArborNet code never explicitly sets the Real Time Clock, it only modifies the local offset.

A ping segment has the following fields:

fNodeID	Node ID of the transmitting node.
fTimeX	Local time of the sending node.
fTimeR	Local time of the receiving node.

TABLE 6. Contents of a SEG_TYPE_PING packet

The purpose of the SYNC thread is to broadcast the node's local time to its immediate neighbors quasi-periodically. The thread first pauses for a randomly chosen amount of time between 0.5 and 1.5 seconds then generates a packet containing a single ping segment (of type SEG_TYPE_PING). Although the segment contains a structure slot for the local time (fTimeX), it isn't filled in yet. The packet is installed in the MAC queue for transmission like any other packet.

The MAC contains code for special handling of SEG_TYPE_PING segments. At the onset of *every* transmission, the MAC code caches the local time. While the packet is being copied into the transmit buffer for processing by BART, if a segment of type SEG_TYPE_PING is detected, the previously cached time is written into the

fTimeX slot of the segment. This technique eliminates any timing jitter introduced by the MAC exponential backoff mechanism.

Similarly, upon receipt, the Radio Receive mechanism caches the local time when a packet first starts to arrive. In the course of reading the packet, if the Radio Receive code detects a segment of type SEG_TYPE_PING, then it copies the cached local time into the fTimeR slot. The packet is then installed in the Application Receive queue like any other packet. This technique eliminates any timing error that would result while the packet sits waiting for processing in the Application Receive queue.

When the Application Receive thread eventually dequeues the packet, it is passed to the synchronization mechanism for processing. There, the error between fTimeX and fTimeR is computed and the system clock is advanced or retarded by one half of the error.

In addition to its role as keeper of local time, the synchronization system also maintains statistics on how many ping packets were sent, how many were received, and a measure of the maximum timing error observed recently. These statistics are made available for transmission in a SEG_TYPE_TIME segment whenever the application transmit thread requests them.

Field tests and results

ArborNet was subjected to field tests in two different locales. The first tests were conducted in a residential setting, for which the nodes were placed around the author's house and garden. Other tests were conducted in an office setting: the nodes were distributed around the fourth floor of the MIT Media Laboratory.

A summary of the tests are show in Table 7, below.

Test name	Locale	Start Time	End Time	Duration	# nodes
Residential I	Residence	01:16	08:04	7h50m	15
Residential II	Residence	08:15	12:15	4h00m	15
Office I	Media Lab	21:00	00:00	3h00m	21

TABLE 7. Field test overview

In each test, node A ("Aspen") was designated as the collection point and gateway for ArborNet data. Its serial port was connected to a laptop computer which was used to log the incoming data for subsequent analysis. Tests ranged from three hours to nearly eight hours, during which time over five megabytes of raw data were collected.

The logged data consists of reports from each node in the network as it was received wirelessly at the central collection point. Reports gave a historical view of the state of each node at ten-second intervals, describing the node's cost tables, synchronization status, packet reliability statistics, on-chip temperature and system battery voltage.

Topology tests

As part of the GRAd routing mechanism, each node maintains a cost table indicating the cost (or number of hops) required to relay a packet to a particular destination. This cost estimate is formed by observing how many hops were previously required to receive a packet from the destination node. Inherent in this technique is the assumption of symmetrical communication channels: if node X can receive packets from node Y, then it is assumed that node Y can receive packets from node X. In practice, radio links are not symmetrical.

Since each node reports its routing costs for all the other nodes, and since that data is collected at a single point, it is possible to derive full connectivity graphs for the network. Two such snapshots are shown below in Table 8 and Table 9. Each row

displays one node's costs, measured in hops, to the node in each column. An asterisk indicates an unknown cost. If the system has completely symmetrical links, the graph will be symmetrical around the diagonal.

A few things can be observed from these graphs. Nodes E, G, P, and U (aka Elder, Ginkgo, Pear, Sycamore, and Uri) were not active during these tests, and as the gateway, node A (Aspen) did not log reports on itself.

The smaller network deployed in the residential setting displays nearly perfect symmetry. Few of the paths require more than one hop and the physical environment didn't pose a challenge to RF communications: the paths were short and there were no significant sources of RF interference.

S\D	A	В	C	D	E	F	G	Н	I	J	K	L	M	N	0	P	Q	R
A	0																	
В	1	0	1	1	*	1	*	1	1	1	2	1	1	1	2	*	1	1
C	1	1	0	1	*	1	*	1	1	1	1	1	1	1	2	*	1	2
D	1	1	1	0	*	1	*	1	1	1	2	1	2	2	2	*	2	2
Е	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
F	1	1	1	1	*	0	*	1	1	1	2	1	1	1	2	*	1	1
G	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Н	1	1	1	1	*	1	*	0	1	1	2	1	1	1	2	*	1	1
I	1	1	1	1	*	1	*	1	0	1	2	1	1	1	2	*	1	1
J	1	1	1	1	*	1	*	1	1	0	2	1	1	1	2	*	1	1
K	2	1	1	2	*	1	*	1	2	2	0	1	1	1	2	*	1	2
L	1	1	1	1	*	1	*	1	1	1	1	0	1	1	2	*	1	2
M	1	1	1	1	*	1	*	1	1	1	1	1	0	1	1	*	1	2
N	1	1	1	2	*	1	*	1	1	1	1	1	1	0	1	*	1	1
О	2	2	2	2	*	2	*	2	2	2	2	1	1	1	0	*	1	2
P	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Q	1	1	1	2	*	1	*	1	1	1	1	1	1	1	1	*	0	2
R	2	1	2	1	*	1	*	1	1	1	2	2	2	2	2	*	2	0

TABLE 8. Connectivity graph for Residential I and II tests

The cells of the table that correspond to asymmetrical links are highlighted in gray in these tables. For clarity, only cells on the lower diagonal of the table are highlighted.

The connectivity graph for the Office I test paints a different picture, as seen in Table 9 below.

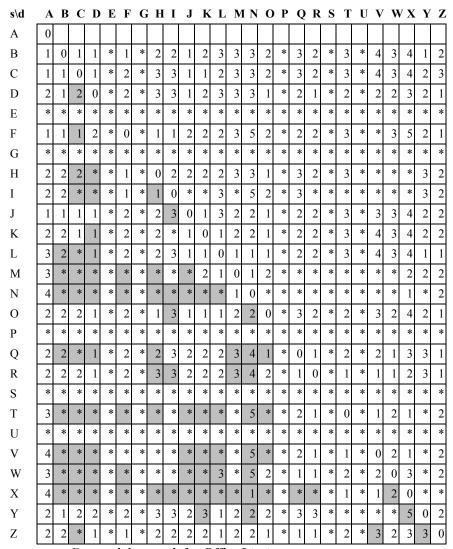


TABLE 9. Connectivity graph for Office I test

The network is not only larger, but the paths are longer and asymmetry is prevalent. The Media Lab is a modern office building with concrete load-bearing walls, metal doors and equipped with wireless networking gear competing in the same 915MHz frequency band as the ArborNet transceivers.

A diagram of the physical layout of the Media Laboratory and the placement of the nodes offers some additional insights to the network, shown below in Figure 24.

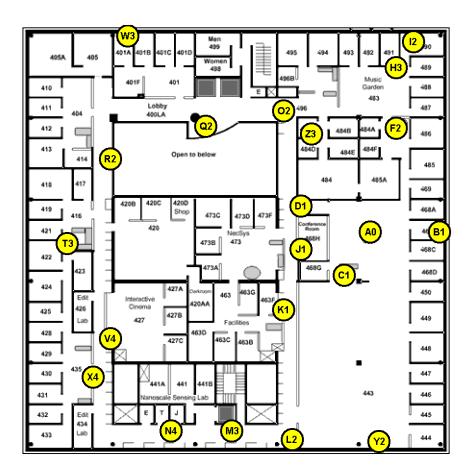


FIGURE 24. Layout of nodes in Office I test

Each circle represents the placement of a node. The letter is the node ID, the number is the number of hops from the central collection point (node A) located in Room 468 towards the east side of the building.

One thing to note is that physical distance is not necessarily a good indicator of the number of hops requires to relay a message. For example, node H (Holly) reported a cost of three hops to relay a message to node A, while node I (Ironwood) required only two hops, even though it was further away and on the far side of a metal door.

Received packet error rates

Each node keeps statistics on packets transmitted and received and reports these statistics back to the data collection node in SEG_TYPE_STATS packets. One set of statistics is maintained by the radio receive process, and simply logs how many packets are received with valid CRCs and how are invalid. A rough measure of the quality of reception at each node can be had by computing

$$\frac{validPackets}{validPackets + invalidPackets}$$
 (EQ 13)

This success rate for the Office I is shown for each node below in Figure 25. These figures do not account for packets with damaged synchronization headers since such packets are filtered out by the BART radio interface chip without notifying the host processor.

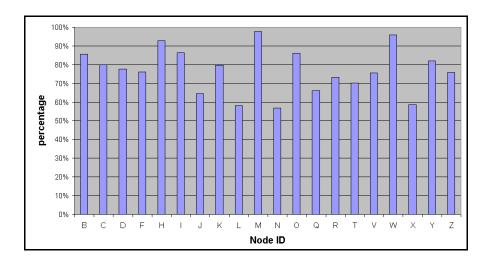


FIGURE 25. Percentage of packets received with valid CRC

It can be seen that nodes J, L, N, and X have marginal reception, as evidenced by their low percentage of valid packets received. Although not shown in the floorplan, nodes L, N and X are relatively isolated and separated from other nodes by steel fireproof doors, which could account for their poor reception. It is not clear why node J has poor reception. It is located near a 915MHz wireless network access point, but so are nodes D and K, which didn't suffer from poor reception.

Goodput tests

While the number of valid packets received is one way to characterize the network, it doesn't answer how successful the network is in relaying messages back to a central collection point. A more significant measure is the ratio of the number of packets originated at each node versus the number of good packets received at the collection point, or the "goodput."

Nodes were programmed to transmit a status report to the central collection node approximately once every ten seconds, so in the course of a three hour test one would expect 1062 reports from each node. An examination of the log files show that three nodes stopped transmitting before the full three hours had elapsed, so in measuring the goodput, number of transmitted nodes was prorated by the duration of the each node's lifetime. Figure 26, below, shows the goodput for each node.

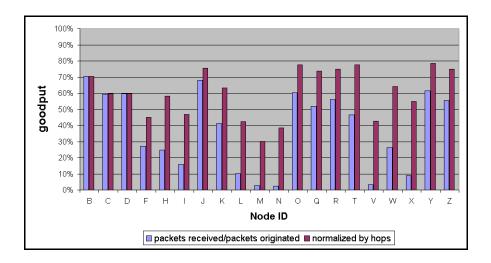


FIGURE 26. Goodput versus node

For each node, two values are shown: one is the goodput, which is simply the ratio of the number of packets received to the number of packets originated. The other value is the goodput normalized by the number of hops:

$$norm = goodput^{1/(hops)}$$
 (EQ 14)

which is a measure of the average reliability of each link independent of the number of hops.

This goodput shows some unexplained anomalies compared to Figure 25. For instance, node J showed a high percentage of bad received packets (as seen in Figure 25), yet is among the most successful at delivering packets to the collection point (Figure 26). It is possible that there is something about the placement or even the fabrication of the node that makes its radio receiver less sensitive.

By contrast, Figure 25 showed that Node M was able to receive packets reliably, yet it shows the poorest performance in delivering packets to the collection point.

Looking at the floorplan in Figure 24 offers a hint as to what might be going on.

Packets from node M are relayed through node N, which is demonstrably bad at

receiving packets. It is likely that N is dropping many of the packets that M expects it to relay on its behalf.

Despite these low percentages, most of the network continued to deliver reliable data over the course of the test. Many of the techniques described in GRAd were omitted in these tests, including timing out of cost table entries and Route Repair, so higher goodput should be easily attainable.

Distributed temperature sensing

A network of simple temperature sensors can detect when a house mate is taking a shower or when a cloud passes overhead. Each ArborNet node is equipped with a temperature sensor incorporated into the ADuC microprocessor. The microprocessor itself consumes about 15 mW of power, so it contributes little to the overall heat of the system. When located away from direct sunlight, the air temperature inside the box is a reasonable approximation of the external air temperature, making it a useful tool for measuring the ambient temperature.

For both residential tests, ArborNet nodes were scattered indoors as well as out-doors, so a single data collection point served to measure the entire environment. A plot of the indoor temperatures, measured between 8:15 AM and 12:15 PM on a chilly Cambridge day tells an interesting story, as shown here in Figure 27.

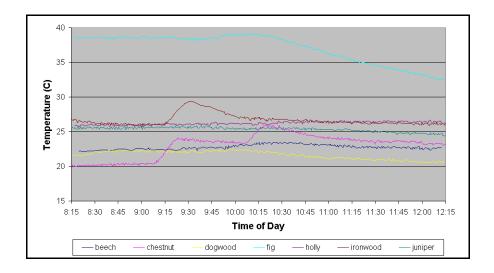


FIGURE 27. Residential II: indoor temperatures

The plot of indoor temperatures shows several significant features. The downstairs rooms (as measured by Beech, Chestnut and Dogwood), are approximately four degrees colder than the upstairs rooms (measured by Holly, Ironwood and Juniper). Ironwood, located in the upstairs bathroom, detected someone taking a shower at 09:15. The water and drain pipes run alongside the downstairs bathroom, causing it to warm up as well (Chestnut). Fig reports that the utility closet, containing the furnace for the baseboard heaters, is a balmy 37 degrees during the night as it struggles to keep the house warm, but cools off by more than ten degrees during the day as the rising outdoor temperatures reduce the thermal burden on the furnace.

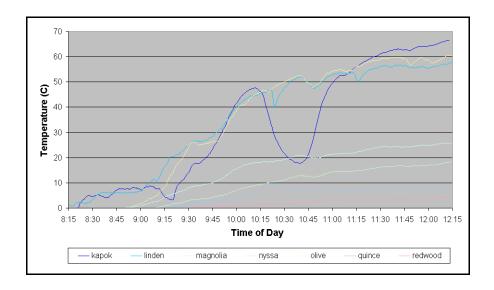


FIGURE 28. Residential II: outdoor temperatures

A plot of the outdoor temperatures, measured by the same network over the same period of time, shows even greater dynamics. The night air was below freezing, but temperatures climbed after sunrise. The temperatures in ArborNet node packages subjected to direct sunlight (Kapok, Linden, Magnolia) rose quickly to above 60 degrees. Kapok was located below a horizontal plank that acted as a gnomon, casting a shadow on it between 10:15 and 11:00 and causing it to cool. A cloud passed overhead around 10:50, as evidenced by a dip in temperature across all of the outdoor nodes.

It is significant that nodes equipped with something as simple as a single temperature sensor can be linked in a distributed network to glean information that would not be possible from more complicated sensors located at a single source.

A temperature graph created from the Office I test shows considerably less movement over time than the residential tests, as shown in Figure 29 below.

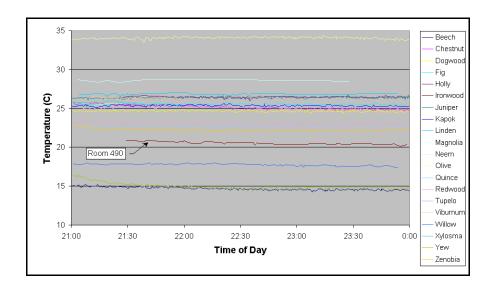


FIGURE 29. Office I: building temperatures

Three of the nodes (Beech, Willow, Yew) are located on metal window sills, so they register a temperature much colder than the rest of the building. Nodes Magnolia and Olive were placed on top of lighted exit signs, thus registering a considerably warmer reading. But one office, Room 490 as reported by Ironwood, clearly stands out as several degrees colder than the rest of the building.

When dense networks of sensors are located in and around office buildings, maintenance personnel can monitor large heating and air conditioning systems continuously and to a level of detail not otherwise possible, which will lead to less wasted energy and happier building occupants.

Battery power: trends and outliers

As previously stated, it is important for nodes in a self-organizing network to be as autonomous as possible. In a typical network, nodes that are powered by batteries can be problematic, since it may not be clear if a loss of communication is due to the batteries running out or due to some other failure.

Nodes in ArborNet include an on-board battery monitor (measured before the voltage regulator), and are programmed to report their battery status regularly to the central data collection point. The table below shows the battery voltages in each node at the start and end of each of the three field tests, as reported wirelessly to the logging node.

	Resident	ial 1	Resident	ial II	Office I		
Node ID	start end		start	end	start	end	
В	4.245	4.138	4.134	4.111	4.050	3.961	
С	4.443	4.250	4.244	4.202	4.212	4.169	
D	4.467	4.263	4.259	4.201	4.216	4.174	
F	3.922	3.859	3.856	3.798	3.740	3.689	
Н	4.536	4.318	4.312	4.260	4.251	4.219	
I	4.527	4.320	4.315	4.265	4.237	4.191	
J	4.488	4.314	4.310	4.261	4.263	4.219	
K	4.429	4.141	4.136	4.217	4.199	4.152	
L	4.259	3.965	3.963	4.164	4.148	4.102	
M	4.496	4.194	4.188	4.228	4.249	4.225	
N	4.536	4.205	4.199	4.177	4.246	4.242	
О	4.548	4.227	4.221	4.279	4.280	4.254	
Q	4.514	4.189	4.182	4.140	4.231	4.188	
R	4.514	4.192	4.186	4.111	4.204	4.165	
T	-na-	-na-	-na-	-na-	4.643	4.488	
V	-na-	-na-	-na-	-na-	4.625	4.578	
W	-na-	-na-	-na-	-na-	4.591	4.423	
X	-na-	-na-	-na-	-na-	4.625	4.565	
Y	-na-	-na-	-na-	-na-	4.698	4.494	
Z	-na-	-na-	-na-	-na-	4.684	4.480	

TABLE 10. Battery voltages before and after each field test.

Even after a total of fifteen hours of service, the voltage in most of the batteries is still over 4.1 volts. It is clear that node B and F (Beech and Fig) were used for additional tests before the start of the field tests, and that the batteries in nodes T through Z (Tupelo through Zylosma) were fresh at the start of the Office I test.

Being able to continuously monitor the supply voltage of each node has already shown itself to be an important feature in the development and maintenance of battery powered wireless nodes. By reading many nodes at once, it is possible to detect overall trends as well as individual exceptions.

Synchronization

The nodes in ArborNet implement the synchronization techniques described in Chapter 5, "Distributed Synchronization." To verify correct operation of the synchronization algorithm, each node issues regular reports on its synchronization state, indicating the node's local time, the maximum short-term inter-node timing difference, and the number of SEG TYPE PING packets issued and received.

The real time clock on the Constellation board has a resolution of 1/128 of a second, which sets ArborNet's limits of synchronization⁵. The synchronization status reports will only report synchronization to within 3/128 of a second, even while the internal synchronization is more accurate⁶. Consequently, the minimum reported error will be never be less than 23.4 milliseconds.

A graph of the error distribution of the synchronization reports in the Office I test indicate that nodes are synchronized within 300 milliseconds of their neighbors over 93% of the time, shown here in Figure 30.

^{5.} This resolution could easily be improved by using software or hardware phase locked loops.

^{6.} The short-term timing difference decays exponentially as each PING packet is received. The exponential decay is computed using simple integer arithmetic and errors less than 3 are internally truncated to zero. Fixpoint arithmetic would solve the problem handily.

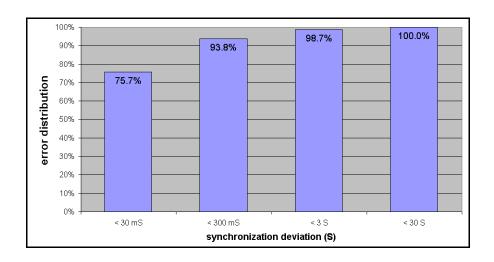


FIGURE 30. Distribution of Synchronization Deviation

However, that there are any errors greater than 300 milliseconds is unexpected. A snapshot of the individual synchronization errors across five nodes offers a some insights, shown below in Figure 31.

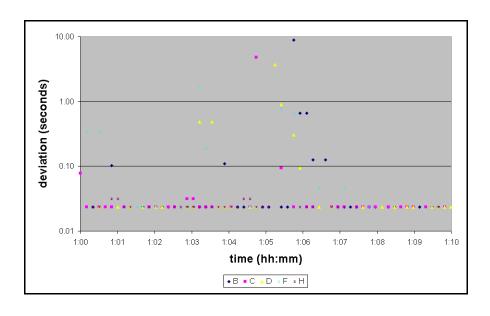


FIGURE 31. Individual synchronization deviation (10 minute snapshot)

Plotted on a logarithmic scale to accentuate the errors, it can be seen that the nodes report the minimum synchronization error (23.4 milliseconds) most of the time, but occasionally report errors in excess of one second. These errors do not appear to be the isolated to individual nodes; whatever the source, the errors spread like small firestorms through all the nodes in the network.

Although the log files don't capture enough information to pinpoint the source, it is possible to make some educated guesses as to the cause of the errors.

One unlikely scenario is that the real time clocks internal to the ADuC824 exhibit sufficient drift that they will fall out of synchronization after a few minutes. If a node is isolated from its neighbors for an extended period of time due to transmission errors, when it finally manages to exchange a SEG_TYPE_PING packet with its neighbors, its internal clock has drifted sufficiently far that it causes a ripple of synchronization error to be propagated through the network. However, the 32.768 KHz crystals used for the Constellation board's timing have an accuracy of 20 parts per million, or about 1.2 milliseconds maximum drift per minute, which doesn't explain the large timing deviations observed in the network.

A more likely cause of these errors is that nodes incorrectly exchange their internal time reference with their neighbors. For example, if the advertised synchronization information was constantly slightly behind the node's internal real time, then all the nodes in the network would retard their internal clocks as a group. However, if one node fell out of communication with other nodes, it would be free to run at the proper speed. When it re-establishes communication with other nodes, it would cause a large perturbation in the overall synchronization of the network.

A solution to this problem will require more detailed data collection and analysis. Despite these occasional timing errors, the fundamental goal has been achieved, showing that nodes can synchronize accurately to one another in a decentralized network.

CHAPTER 8 Conclusions & Future Work

Because it has no other means to communicate, a smoke detector in the basement can only scream when it detects smoke and beep futilely when its batteries run low. Given a more sensible means of expression, it could do a much better job of protecting a home and its occupants.

Microprocessor chips have already reached the point where their usefulness is not limited by their processing power, but rather by a lack of context. Isolated from the rest of the world, the majority of these chips can neither sense the world around them nor participate in any meaningful discourse with other chips in their environment.

Some lessons learned

This thesis has presented *Embedded Networking*, an integrated approach to scalable, self-organizing networks designed to give voice to microprocessors. Several good and surprising results have arisen in the course of developing this art.

Embedded Networks are attainable. Embedded Networks can be built today. A practical implementation does not hinge upon as-yet-undeveloped technologies or exotic components. Because Embedded Networking has been designed to be "radio agnostic," it can use existing radios and still take advantage of the inevitable developments in new wireless technologies.

Data aggregation is a powerful tool. It is astonishing how much can be learned by having multiple data points. As an example, the interplay of outdoor temperatures, measured at just seven different points during the course of a sunrise, told a much more interesting story than seven readings from one sensor possibly could.

Embedded Networks must be proactive. David Tennenhouse is right: if computing systems are to become useful, they must do so with a minimum of attention from their human stewards [Tennenhouse 2000]. For example, it proved to be remarkably useful to have each node in the ArborNet proof of concept system monitor its own battery voltage. This simple approach removed doubts as to whether nodes were running low on power or not. As an unexpected benefit, it proved very easy to answer the question "do alkaline batteries run down faster when they are subjected to sub-freezing temperatures?" (The answer was that they did not drain appreciably faster than their warmer neighbors.)

Gradient Routing works in theory and in practice. Gradient Routing, a cornerstone of the Embedded Networking systems described here, proved itself to be an effective technique. It succeeded in relaying data packets from one wireless node to another without either the need for preplanning the network or for human intervention during its operation.

Unturned Stones

Paradoxically, the hallmark of satisfying research is that it leaves one hungry to do more, and the work here has been no exception. This early exploration into the theory and practice Embedded Networking has perhaps raised one new question for every question answered. A few of these "unturned stones" are offered with the thought that they might prove to be interesting and worthwhile avenues for further research

DEEPEN UNDERSTANDING OF RADIO PROPAGATION

It would be informative to conduct a detailed study of the connectivity characteristics among all nodes in a network, directly measuring the bit error and packet error characteristics between each combination of nodes. Although the error rates will depend upon radio technology and environment, some other questions will fall out as a direct consequence: How symmetrical are wireless communication links in

practice? What is a good estimate of path loss, and how well does spatial division multiplexing work? How closely does physical topography correspond to network topology? This kind of information is typically difficult to gather, but a decentralized multi-hop wireless network such as ArborNet makes it quite easy.

BUILD A WIRELESS SUNDIAL

Chapter 5 described techniques for a community of nodes to agree on a common time base, appropriate for sub-millisecond measurements, but not rooted in any physical time base. Working with ArborNet suggests a somewhat whimsical approach to accurate timekeeping in an unattended network by building a "wireless sundial" from multiple embedded networking nodes.

Each node is powered entirely by solar cells, so it would only wake up when there was sun to measure. Once awake, a node would track the position of a shadow cast by a gnomon using simple photocells, and report the position of the shadow to its neighbors. Using multiple nodes would eliminate errors due to clouds, and on clear days, the network could accurately report both the solar time of day and the day of the year. The system would be guaranteed to be free of any long-term drift.

IMPLEMENT DYNAMIC DUTY CYCLE

Distributed Synchronization is a first step towards power savings. If all nodes in the network can agree on a common time base, they can all sleep at the same time and wake up simultaneously in order to exchange packets during network "business hours."

Assume that nodes draw no power while they sleep and constant power while they are awake, independent of radio activity. Let T_{wake} denote the amount of time that the they are awake and T_{sleep} the time during which they sleep, the duty cycle for the system is then:

$$T_{DC} = \frac{T_{wake}}{T_{wake} + T_{sleep}} \tag{EQ 15}$$

The system power consumed will be reduced by a factor of T_{DC} , while the load on the airwaves will be increase by the same factor.

Since many embedded network applications need only communicate to for a few milliseconds out of every minute, this approach can lead to substantial power savings.

DEVELOP MECHANISMS FOR RELOADING CODE

For all its ease in measuring and gathering data, the Embedded Networks presented here don't offer any mechanism for reloading code over the network. Part of this is due to limitations in hardware: the Constellation boards used in the ArborNet system have no provisions for dynamically reloading code. But a degree of caution influenced the design: one bad byte distributed among all the nodes could immediately bring down the network.

Nonetheless, the value in being able to dynamically reload code in order to conduct different networking tests is obvious. An embedded network system designed to dynamically update its own networking code would be an extremely useful research tool. A longer-term goal would be to create robust mechanisms for dynamically reloading code for applications outside of the laboratory.

Acknowledgements

Entering the Media Laboratory is like embarking on some strange and wonderful journey: When I started five years ago, I didn't know where it would lead me, but I had a hunch that I would have many adventures and encounter some wonderful people along the way. Time has validated my intuition, and in retrospect, I could not have scripted a better cast of characters.

My advisor, Mike Hawley, jarred me loose from my everyday life and into the Lab in the first place, and it is his ongoing vision of building smart, useful objects that has kept me happily working late nights. Committee member and sailing captain Andy Lippman has always offered good criticisms of my work, backed up with sound reasoning. Bill Kaiser, expert in the field of self-organizing networks, has always expressed enthusiasm about my work, sensibly tempering my elation by introducing me to work other people have already done in the field. I've had many stimulating talks with LCS professor Hari Balakrishnan and his students about the finer points of embedded networks—it is wonderful to have a local expert in the field. David Tennenhouse did me a great service by making me promise that I would stay focussed on completing the dissertation before being distracted by the Next Big Thing.

I have been fortunate to have been supported as a Motorola Fellow for much of my time as a Media Lab student. But the support hasn't been simply financial: I've been constantly inspired by my interactions with the engineers and managers of Motorola, and I especially appreciate Sheila Griffin's handling of the program.

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Two people deserve special mention, without whose help I cannot imagine this research coming to fruition. Andy Wheeler designed the Constellation board and many other elegant (though often unsung) hardware systems. Through his own example, Andy has pushed me to think harder and build more. Charlotte Burgess advanced this research in more ways than can be counted, from proofreading and graphic design to emotional and moral support. Charlotte has a talent for asking the question that unties whatever Gordian knot I am struggling with. To both Andy and Charlotte, I give special thanks.

APPENDIX A References

[Abelson 1995] Hal Abelson, Tom Knight, Gerald Sussman. "Amorphous Computing." MIT LCS internal White Paper. Draft of October 14, 1995.

[Abramson 1985] Norman Abramson. "Development or the ALOHANET" IEEE Transactions on Information Theory, Vol. IT-31, pp. 119-123, March 1985.

[Bertsekas 1992] Dimitri Bertsekas, Robert Gallager. "Data Networks" Second Edition. Prentice Hall Englewood Cliffs, New Jersey, 1992. *A dependable textbook on the networking and queuing theory.*

[Bluetooth 1999] Bluetooth specification, available online at http://www.bluetooth.com/developer/specification/specification.asp

[Broch 1998] J. Broch, D. A. Maltz, D. B. Johnson, Y-C. Hu, J. Jetcheva. "A performance comparison of multi-hop wireless ad hoc networking protocols," in *Proceedings of the 4th International Conference on Mobile Computing and Networking (ACM MOBICOM '98)*, pp. 85–97, October 1998.

[Bult 1996] K. Bult, A. Burstein, D. Chang, M. Dong, M. Dielding, E. Kruglick, J. Ho, F. Lin, T. H. Lin, W. J. Kaiser, R. Mukai, P. Nelson, F. L. Newburg, K. S. J. Pister, G. Pottie, H. Sanchez, O. M. Stafsuff, K. B. Tan, C. M. Ward, G. Yng, S. Xue, H. Marcy, J. Yao. "Wireless Integrated Microsensors." Proceedings of the 1996 Hilton Head Transducers Conference, June 1996. *An early paper on Bill Kaiser's excellent WINS program*.

[Carvey 1996] Phillip Carvey. "BodyLAN." IEEE Circuits and Devices, V4 No 12 July 1996. Describes the design for Phil Carvey's ultra low-power radio design—a

nifty bag of tricks that attains $4x10^{-9}$ Joules per received bit and $2x10^{-9}$ Joules per transmitted bit.

[Das 2000] S. Das, C. Perkins, E. Royer. "Performance comparisons of two ondemand routing protocols for ad hoc networks," *Proceedings of the IEEE Conference on Computer Communications (INFOCOM)*, Tel Aviv, Israel, March 2000, pp. 3–12.

[Demers 1994] Alan Demers, Scott Elrod, Christopher Kantarkiev, Edward Richley. "A Nano-Cellular Local Area Network Using Near-Field RF Coupling." CSL-94-8 Xerox Corporation, Palo Alto Research Center. October 1994. *Describes a nobel radio system developed at Xerox PARC as part of their Ubiquitous Computing program. They essentially use inductively coupled systems and exploit the rapid falloff for high-density wireless systems.*

[emWare 2000] Documentation available online at http://www.emware.com/solutions/emit/. emWare makes a suite of "thin clients" that run on small microcontrollers connected (generally via wired links) to larger systems that act as proxies.

[Fall 1998] K. Fall and K. Varadhan (editors) "ns Notes and Documentation." Lawrence Berkeley Nantional Laboratories, August 1998. Available online at http://wwwmash.cs.berkeley.edu/ns/. *ns has become is the industry standard for quantifying the performance of network protocols.*

[Gershenfeld 1999] N. Geshenfeld. "When Things Start To Think." Henry Holt and Company, New York, 1999. *Articulates the vision of Things That Think*.

[Heidegger 1968] Martin Heidegger (translators John Macquarrie and Edward Robinson). "Sein und Zeit." Harper & Row, San Francisco. 1962. This famous existentialist starts with first principals in describing the relation of humans to the world around them. As such, he has a greater influence in the topic of user interfaces than some might imagine.

[Heinzelman 2000] W. Rabiner Heinzelman, A. Chandrakasan, and H. Balakrishnan "Energy-Efficient Communication Protocol for Wireless Microsensor Networks," Proceedings of the 33rd International Conference on System Sciences (HICSS '00), January 2000. This paper describes LEACH (Low Energy Adaptive Clustering Hierarchy), a technique that dynamically chooses local cluster heads in multi-hop, ad hoc networks in order to balance and reduce the total amount of energy spent by individual nodes.

[IEEE 1999] IEEE Std. 802.11, 1999 Edition. "Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications." IEEE Standards Association, 1999. ISBN 0-7381-1809-5 Description of 802.11 wireless LAN standard

[Intanagonwiwat 2000] Chalermek Intanagonwiwat, Ramesh Govindan, and Deborah Estrin. "Directed Diffusion: A Scalable and Robust Communication Paradigm for Sensor Networks." Proceedings of the Sixth Annual International Conference on Mobile Computing and Networks (MobiCOM 2000), August 2000.

[IrDA 1998] Infrared Data Association, IrDA specification, available online at http://www.irda.org

[Johansson 1999] P. Johansson, T. Larsson, N. Hedman, B. Mielczarek. "Routing protocols for mobile ad hoc networks—a comparitive performance analysis," *Proceedings of the 5th International Conference on Mobile Computing and Networking (ACM MOBICOM '99)*, pp. 195-206, August 1999.

[Johnson 1996] D. B. Johnson, D. A. Maltz. "Dynamic source routing in ad hoc networks," in *Mobile Computing*, T. Imielinski and H. Korth, Eds., Kulwer, 1996, pp. 152-81.

[Kelly 1997] Kevin Kelly. "New Rules for the New Economy." Wired Magazine, 5.09 pp 140-197, September 1997. Kevin Kelly's vision, not just of a world densely populated with smart devices, but how these devices will change the rules.

[Kleinrock 1987] Leonard Kleinrock and John Silvester. "Spatial reuse in multihop packet radio networks." Proceedings of the IEEE, 75(1):156-167, January 1987. MANET was not the first foray into multi-hop packet radio systems.

[Kramer 1999] K. H. Kramer, N. Minar, P. Maes. "Tutorial: Mobile Software Agents for Dynamic Routing," *Mobile Computing and Communications Review (ACM SIGMOBILE)*, vol. 3, no. 2, 1999, pp. 12–16.

[Kumar 2000] S. Kumar. "Sensor Information Techology (SenseIT) Program", described in http://www.darpa.mil/ito/research/sensit/, DARPA Information Technology Office, April 2000.

[Macker 2000] J. Macker, S. Corson. "Mobile Ad-hoc Networks (manet) Charter." http://www.ietf.org/html.charters/manet-charter.html, February 2000

[Metcalfe 1976] Robert M. Metcalfe and David R. Boggs. "Ethernet: Distributed packet switching for local computer networks." Communications of the ACM 19, 7 July 1976, pp 395-404. *One of the original papers on Ethernet.*

[Mills 1991] David L. Mills. "Internet time synchronization: the Network Time Protocol." IEEE Trans. Communications COM-39, pages 1482-1493, October 1991. *Available online as* http://www.eecis.udel.edu/~mills/database/papers/trans.ps

[Minar 1999] Nelson Minar, Matthew Gray, Oliver Roup, Raffi Krikorian, Pattie Maes. "Hive: Distributed Agents for Networking Things." Presented at ASA/MA August 1999. Available on-line as http://www.hivecell.net/hive-asama.html

[Moravec 1998] Hans P. Moravec. Robot: mere machine to transcendent mind. Oxford University Press, November 1998. *Has an excellent graph of MIPs per dol-*

lar. See also the online WEB pages for regularly updated numbers: http://www.frc.ri.cmu.edu/~hpm/book97/ch3/processor.list

[Pentland 1996] Alex P. Pentland. "Smart Rooms." Scientific American, 274(4) pp. 68-76. April 1996. At the time this article was published, Pentland made a convincing argument that computational systems of were sensorially deprived. Five years later it still holds true.

[Perkins 1999] C. Perkins and E. Royer. "Ad-hoc on-demand distance vector routing," *Proceedings of the 2nd IEEE Workshop on Mobile Computing Systems and Applications*, pp. 90–100, February 1999.

[Poor 2001] R. Poor. "Jasper: a Java-based dynamic simulator for ad hoc wireless networks," unpublished.

[Simon 1969] Herb Simon. "The Sciences of the Artificial." MIT Press, Cambridge Massachusetts, 1969. Economics meets Artificial Intelligence meets Complexity Theory, offering useful tools for thinking about problems. A wonderfully readable survey of Simon's work.

[Stajano 1999] Frank Stajano and Ross Anderson. "The Resurrecting Duckling: Security Issues for Ad-Hoc Wireless Networks." Chapter in Security Protocols, 7th International Workshop Proceedings, Lecture Notes in Computer Science, 1999. Springer-Verlag Berlin Heidelberg 1999. Describes techniques for "imprinting" in wireless devices in ad-hoc networks can be "imprinted" to describe ownership and other security attributes.

[Sun 2000] Sun Microsystems. "JINI Architecture Specification, Version 1.1." available online at http://www.sun.com/jini/specs/

[Tennenhouse 2000] David Tennenhouse. "Proactive Computing." Communications of the ACM, May 2000, Volume 43, #5. David makes the argument that since there are so many embedded computers, they must operate autonomously and sen-

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sibly—humans must be able to "get out of the loop." This issue of CACM is dedicated to the topic of "Embedding The Internet."

[UMTS 2000] Information available online at http://www.umts-forum.org. *UMTS* (universal mobile telecommunication system) is being being developed by the International Telecommunications Union as the successor to GSM cellular telephone systems, featuring bandwidths between 144KBps and 2MBps.

[Weiser 1991] Mark Weiser. "The Computer for the Twenty-First Century." Scientific American, 265(3) pp. 94-104, September 1991. Mark Weiser's famous paper on Ubiquitous Computing. It still make good sense after all these years, and reminds us of some of the things we are trying to attain.

[Wheeler 2000] Andy Wheeler, Aggelos Bletsas. "Energy Efficiency Study of Routing Protocols for Mobile Ad-hoc Networks" Final project paper for 6.899 Computer Networks, taught by Professor Hari Balakrishnan.

[W3C 2000] World Wide Web Consortium (W3C). "Extensible Markup Language (XML) 1.0" second version edition 6 October 2000. Available on the web at http://www.w3.org/TR/REC-xml

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APPENDIX B ArborNet Host Code Listing

Following is the ArborNet C source code that is executed by the ADuC824 host processor on the Constellation board. More information on the ArborNet system can be found in Chapter 7.

```
#define ADC_H
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              #ifndef ADC_H
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      All
```

```
#endif
                                                                           pkt_t xdata *adc_report(pkt_t xdata *next);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              #include "pkt.h"
                                                                                                                                    void adc_init();
                                                                                                                                                                                                                                                                                                                        typedef struct
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // routines to read, packetize, print the analog to digital converter
                                                                                                                                                                                                                                                                                                                                                                               // chip temperature on aux
                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // thermistor (external temp) on AIN1 (primary)
                                                  // create packet and fill with a fresh set of readings
                                                                                                                                                                                                                                                                                                                                                                                                             // Battery monitor on AIN4
                                                                                                                                                                                                                                                                                                                                                                                                                                      // photocell on AIN1 (aux)
                                                                                                                                                                                         adcPayload;
                                                                                                                                                                                                                    unsigned int
                                                                                                                                                                                                                                             unsigned int fIntTemp;
                                                                                                                                                                                                                                                                      // unsigned int fLight;
                                                                                                                                                                                                                                                                                               // unsigned long fExtTemp;
                                                                                                                                                                                                                    fVBATMon;
                                                                                                                                                                                                                                                                                                                                _adcPayload {
                                                                                                                                                                                                                                                                                                                                                                                                             (aux)
```

File: adc.c

```
// -*- Mode: C++ -*-
// File:
    adc.c
// Description: routines to read the A/D converters
// Description: routines to read the A/D converters
// Copyright 2001 by the Massachusetts Institute of Technology. All
// rights reserved.
// This MIT Media Laboratory project was sponsored by the Defense
// Advanced Research Projects Agency, Grant No. MOA972-99-1-0012. The
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```
#define PHOTOCELL_CHANNEL 0x00
#define VBATMON_CHANNEL 0x10
#define CHIPTEMP_CHANNEL 0x20
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       static void adc_read_secondary(unsigned char adlcon) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         #define AIN5_CHANNEL 0x30
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // full scale until VBAT drops to less than 1.25V.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       #include "screen.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      #include
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           #include
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       #include <rtx51tny.h>
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              #include "arbor.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  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Permission to use, copy, or modify this // software and its documentation for educational and research
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        void adc_read(adcPayload xdata *ap) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // internal routines
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // NOTE: With the current board design, VBATMON will stay pegged at
// ADOCON = BITMASK(0,0,0,0,0,1,1,1,1);
// ADMODE = BITMASK(0,0,1,0,0,0,1,0);
// RDY0 = 0; // start
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     // adcPayload structure, passed by reference.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    while (!RDY1) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           RDY1 = 0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         ADMODE = BITMASK(0,0,0,1,0,0,1,0); // secondary, single shot
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // take a reading of the four analog sources: photocall, battery
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                                                                                                                                                                                                                                                                                                            // thermistor is on primary A/D...
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // monitor, chip temperature, and thermistor.
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             warranty.
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            os_wait2(K_TMO, 1); // buzz...
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              <stdio.h>
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/* AIN4 */
         // start conversion on primary A/D
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   /* AINTEMP */
/* AIN5 */
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // for os_wait()...
// aduc register defs
// leds, etc
                                                                                              // AIN1-GND, unipolar, 2.56V
// primary, single shot
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            Store results in
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               μ
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pkt_t xdata *adc report(pkt_t xdata *next) {
   // allocate a packet, take a set of readings. Note that adc_r
   // is asynchronous, and may take significant time to complete.
   pkt_t xdata *pkt = pkt_alloc();
                                                                                                                                                                                                                                                                                                                                                                                             void adc_init() {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // published routines
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       pkt_size(pkt) = sizeof(adcPayload);
adc_read((adcPayload xdata *)pkt_payload(pkt));
pkt_next(pkt) = next;
                                                                                                                                                                                                                                                                                                                                        SF = 0x0d;
return pkt;
                                                                                                          pkt_type(pkt) = SEG_TYPE_ADC;
                                                                                                                                                                                                                                                                                                                                                            // fastest, noisiest input
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  ap->fVBATMon = (AD1H << 8) | AD1L;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           adc_read_secondary(BITMASK(0,0,0,0,1,0,0,0) | VBATMON_CHANNEL);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 ap-fIntTemp = (AD1H << 8) \mid AD1L;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        adc_read_secondary(BITMASK(0,0,0,0,1,0,0,0) | CHIPTEMP_CHANNEL);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // ap->fExtTemp <<= 8;
// ap->fExtTemp |= ADOL;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     // ap->fExtTemp <<= 8;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // while (!RDY0) {
// os_wait2(K_TM)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // ap - > fExtTemp | = ADOM;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              adc_read_secondary(BITMASK(0,0,0,0,1,0,0,0) | PHOTOCELL_CHANNEL);
ap->fLight = (AD1H << 8) | AD1L;</pre>
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                os_wait2(K_TMO, 1);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     // buzz...
                                                                                                                                                                                              Note that adc_read()
```

File: appr.h

```
void appr_didXmit(pkt_t xdata *pkt);
                                                                                                                                                                                                                                                                                                                                                                                                            void appr_recvPkt(pkt_t xdata *pkt);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       #include "pkt.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                #define APPR_H
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         #ifndef APPR_H
// passed to the radio and just before it is freed.
                                                                                                                                                                                    // application receive thread.
                                                                                                                                                                                                                            // void appr_task(void) _task_ APPR_TASK {
                                                                                                                                                                                                                                                                                                                  // the receive process
                                                                                                                                                                                                                                                                                                                                                               // stuff a received packet into the receive queue, notify
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // For general public use
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          product without first obtaining appropriate licenses from MIT. MIT makes no representations about the suitability of this software for
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File: appr.c

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#include "vector.h"
                                                                                                                                                                                                                                                                                                           #include
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 #include "adc.h"
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<rtx51tny.h> <stdio.h>
                                                                                                                                                                                                                                                                                                                                          "costTable.h"
                                                                                               "stats.h"
                                                                                                                                                                                                                                          "sync.h"
                                                                                                                                                                                                                                                                                                                                                                            "arq.h"
                                                                                                                                                                                                                                                                                                                                                                                                              "arbor.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                               "appx.h"
                                                                                                                                       "screen.h'
                                                                                                                                                                                                        "pkt.h"
                                                                                                                                                                                                                                                                            "id.h"
                                                                                                                                                                                                                                                                                                        "grad.h"
                                                                                                                                                                      "mac.h"
                                 // for os_wait()...
                                                                                                                                                                                                                                                                                                                                             // ct_costTo()
                                                                                                                                                                                                                                                                                                        // grad_seqno()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           Permission to use, copy, or modify this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     For any other uses of this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            A11
```

```
void appr_recvPkt(pkt_t xdata *pkt) {
    // handle a packet received by the radio process by putting in the
    // APP receive queue and notifying the APR task. Normally called
    // from within RADR_TASK
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          void appr_task(void) _task_ APPR_TASK {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // the queue fills up, dump the oldest. // \#\# must not be called until APPR_TASK has been started
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  static void appr_servicePkt(pkt_t xdata *pkt, pkt_t xdata *gradSeg);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // it.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    DEFINE_VECTOR(gAppRQueue, APPR_QUEUE_SIZE);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         #define APPR_QUEUE_SIZE 10
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // (the application receive thread)
//
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // the packet to the various services that might want to know about
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      // Queue up a received packet. Packets are put here by the radio
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // Wait for a packet to arrive in the receive queue, then distribute
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // Application Receive task
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // receive thread and are removed by the application process.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             pkt_free(vector_shove(VECTOR(gAppRQueue), pkt));
// stats_appQueuePkt(vector_count(VECTOR(gAppRQueue)));
os_send_signal(APPR_TASK); // notify app task there's a packet
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // one-time initialization of the application's receive queue vector_init(VECTOR(gAppRQueue), APPR_QUEUE_SIZE);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     while (1) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      pkt_t xdata *pkt;
pkt_t xdata *gradSeg;
                                                                                                                                                                                                                                                                                                                                                                                                               gradSeg = grad_find_segment(pkt);
if (gradSeg == NULL) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  else if (!grad_segIsFresh(gradSeg)) {
                                                                    else {
                                  if (grad_isForMe(gradSeg)) {
                                                                                                                                      pkt_free(pkt);
                                                                                                                                                                     // packet is stale - drop now
SCREEN_TASK(("stale"));
                                                                                                                                                                                                                                                                                                              pkt_free(pkt);
                                                                                                                                                                                                                                                                                                                                              appr_servicePkt(pkt, gradSeg);
                                                                                                                                                                                                                                                                                                                                                                                // no routing header? Pass it along anyway...
appr_servicePkt(pkt, gradSeg);
```

```
void appr_didXmit(pkt_t xdata *pkt) {
   // Called after pkt has been transmitted by the radio, appr_didXmit()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      #endif
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   static void appr_servicePkt(pkt_t xdata *pkt, pkt_t xdata *grad) {
   // always print received packet in hex on serial port
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  #ifdef SCREEN ENABLE
arq_didXmit(pkt);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       pkt_dumpHex(pkt);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           screen_goto(14, 1);
                         // a copy of any packets that need rescheduling
                                              //\ gives individual services a chance to take some action when the //\ transmission has finished. Notably, arg needs a chance to grab
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       while (pkt != NULL) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // do additional servicing as needed
                                                                                                                                                                                                                                                                                                                                                                                                                       Case SEG_TYPE_TEXT:
    case SEG_TYPE_COST_L:
    case SEG_TYPE_STAITS:
    case SEG_TYPE_ADC:
                                                                                                                                                                                                                                                    pkt = pkt_next(pkt);
                                                                                                                                                                                                                                                                                                                                                                      default:
                                                                                                                                                                                                                                                                                                                                                                                           case SEG_TYPE_TIME:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             case SEG_TYPE_PING:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                case SEG_TYPE_APPX:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        case SEG TYPE ARQ:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       case SEG_TYPE_DISCOVERY:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 case SEG_TYPE_GRADIENT:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              switch (pkt_type(pkt)) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  case SEG_TYPE_ACK:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       break;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               sync_serviceSeg(pkt);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          break;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              appx_serviceSeg(pkt);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            break;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    break;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        grad_relayIfNeeded(pkt, gradSeg);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // relay or drop the message. Either w
// to be freed by grad_relayIfNeeded().
                                                                                                                                                                                                                                                                                                                break;
                                                                                                                                                                                                                                                                                                                                       // contents of the packet has already been printed (above)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      arq_serviceAck(pkt);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               break;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      arq_serviceArq(pkt, grad);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // grad updates already happened in appr_task() above
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                Either way, pkt is guaranteed
```

File: appx.h

```
void appx_stopReporting();
                                                                                                                                                                                                                                                                                                                                                                                                                                                              typedef struct _appxPayload {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            #include "pkt.h"
// sending reports
                                                                                                                                                                                                                                                       void appx_startReporting(node_id destination);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      #include "arbor.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              #define APPX_H
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    #ifndef APPX_H
                                                                                                                                                                   // sending reports to the named destination node.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // node to a designated collection point.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // Application Transmit process periodically sends info from this
                                      // broadcast a SEG_TYPE_APPX to all nodes, asking them to stop
                                                                                                                                                                                                             ^{\prime}/ broadcast a SEG_TYPE_APPX to all nodes, asking them to start
                                                                                                                                                                                                                                                                                                                                    } appxPayload;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // For general public use
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           / File:
                                                                                                                                                                                                                                                                                                                                                                                 unsigned int fDelayTics;
                                                                                                                                                                                                                                                                                                                                                                                                                           node_id fHost;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          or adapted as the basis of a commercial software or hardware
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          copies and supporting documentation. If individual files are
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        This distribution is approved by Walter Bender, Director of the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          Copyright 2001 by the Massachusetts Institute of Technology.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      Description: Application Transmit support
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  product without first obtaining appropriate licenses from MIT. MIT makes no representations about the suitability of this software for
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       be obtained from MIT.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       software,
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    separated from this distribution directory structure, this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          purposes only and without fee is hereby granted, provided that this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            software and its documentation for educational and research
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      Advanced Research Projects Agency, Grant No. MOA972-99-1-0012.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    -*- Mode: C++ -*-
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            any purpose.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      to distribution in whole or in part, specific prior permission must
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        copyright notice and the original authors' names appear on all
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                content of the information does not necessarily reflect the
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    rights reserved
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    in original or modified form, including but not limited
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            It is provided "as is" without express or implied
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                These programs shall not be used, rewritten,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              Permission to use, copy, or modify this
                                                                                                                                                                                                                                                                                                                                                                                 // host to send data to
// inter-report delay (in system tics)
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              All
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          The
```

```
pkt_t xdata *appx_makeSeg(pkt_t xdata *next, node_id host);
// allocate a appx segment, link it in with next

void appx_serviceSeg(pkt_t xdata *seg);
// act upon an incoming appx message
#endif
```

File: appx.c

```
#include "adc.h"
                                  #include
                                                                                                                                                                                                                                                             #include
                                                                                                                                                                                                                                                                                                                                                                                                       #include
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      #include
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     #include
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      #include "arq.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         #include "appx.h"
                                                                                                                                                     #include
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        #include
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                #include "constell.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          warranty.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      Media Laboratory, MIT. Permission to use, copy, or modify this software and its documentation for educational and research
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         any purpose.
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       This MIT Media Laboratory project was sponsored by the Defense
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     rights reserved.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      Description: Application Transmit: generate periodic reports
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           software, in original or modified form, including but not limited
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              copyright notice must be included. For any other uses of this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    copyright notice and the original authors' names appear on all
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        This distribution is approved by Walter Bender, Director of the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 For general public use.
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 content of the information does not necessarily reflect the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    Advanced Research Projects Agency, Grant No. MOA972-99-1-0012.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        Copyright 2001 by the Massachusetts Institute of Technology.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       -*- Mode: C++ -*-
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        "costTable.h"
"stats.h"
                                                                                                                              "screen.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          "grad.h"
                                                                                                                                                                                                                                                                         "sync.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           "id.h"
                                                                                                                                                                                                                                                                                                                                                                                            "mac.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              appx.c
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              It is provided "as is" without express or implied
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      // for ct_report(), ct_reset_except()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // for arq_makeArq()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           A11
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           The
```

```
void appx_serviceSeg(pkt_t xdata *seg) {
// When a SEG_TYPE_APPX packet is received, copy the appxPayload to
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         pkt_t xdata *appx_makeSeg(pkt_t xdata *next, node_id host) {
   // create a SEG_TYPE_APPX packet, requesting that nodes send periodic
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // set a limit to the minimum delay between appx reports \#define\ MIN\_APPX\_DELAY\ (OS\_TICS\_PER\_SECOND/2)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // Note that even though there's a slot in an appxPayload packet
// specifically to control the delay time between appx reports, it
// will always be set to DEFAULT_APPX_DELAY. This could be made
// variable, if needed.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  static appxPayload sDirectives;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               #include <rtx51tny.h>
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                void appx_stopReporting() {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 BROADCAST_NODE));
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  void appx_startReporting(node_id destination) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     #define DEFAULT_APPX_DELAY 1060
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    #include <string.h>
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      #include <stdlib.h>
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                #include <stdio.h>
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        #include <limits.h>
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // sDirectives stores the recipient for reports and the report interval
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               pkt_t xdata *seg = pkt_alloc();
appxPayload xdata *xp = pkt_payload(seg);
pkt_type(seg) = SEG_TYPE_APPX;
pkt_size(seg) = sizeof(appxPayload);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 mac_xmitPkt(grad_makePkt(appx_makeSeg(NULL, 0), BROADCAST_NODE));
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    mac_xmitPkt(grad_makePkt(appx_makeSeg(NULL, destination),
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // broadcast a SEG_TYPE APPX to all nodes, asking them to start // sending reports to the named destination node.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        return seg;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              pkt_next(seg) = next;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             xp->fDelayTics = DEFAULT_APPX_DELAY;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   xp->fHost = host;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // sending reports
appxPayload xdata *xp = pkt_payload(seg);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // reports to <host>
                                                                                                                                                    // information and routing table info for the node. Short of creating
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // broadcast a SEG_TYPE_APPX to all nodes, asking them to stop
                                                                                                                                                                                                                                                                         // the header.
                                                                                                                                                                                          As a side effect, an APPX packet also resets all the statistics
                                                                               the logging and statistics info.
                                                                                                                                                                                                                                                                                                        start sending the requested information to the host specified in
                                                                                                                 a new packet type, this is the only convenient way to clear all
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // rand()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     // for os_wait()...
// printf
```

```
sDirectives.fDelayTics));
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        static void _wrapAndSend(pkt_t xdata *pkt) {
    // "Decorate" pkt with a request for reply (arq) and a grad
    // header before passing it to the MAC system for transmission.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                void appx_task(void) _task_ APPX_TASK {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              static void _bide(unsigned int tics) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // then start sending periodic updates.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // Wait until we're directed to send our status to a particular host,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     mac_xmitPkt(grad_makePkt(arq_makeArq(pkt), sDirectives.fHost));
LED_OFF(GREEN_LED);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       LED_ON(GREEN_LED);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         sDirectives.fDelayTics = 0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          while (tics != 0)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      os_send_signal(APPX_TASK);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       ct_reset_except(xp->fHost);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           sync_reset();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                stats_reset();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     memcpy(&sDirectives, xp, sizeof(appxPayload));
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       while (1) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              sDirectives.fHost = 0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // one-time initialization
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // approx 9.6 mSec, or 106 tics per second
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         SCREEN_TASK(("appx_ss()")); PKT_PRINT(seg);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // wait for the given number of tics to elapse.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              os_wait2(K_TMO, t);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  unsigned char t = (tics > UCHAR_MAX)?UCHAR_MAX:tics;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                tics -= t;
                                                                                                                                                                                                                                                                                                SCREEN_TASK(("h=%bx d=%0bx", sDirectives.fHost,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            SCREEN_TASK(("appx_task(1)"));
_wrapAndSend(ct_report_h(sync_report(NULL)));
                                                                                                          _bide(sDirectives.fDelayTics);
                                                                                                                                                                                      // I: send low half of cost table and sync state
                                                                                                                                                                                                                                                                                                                                                                                                                                            if (sDirectives.fDelayTics < MIN_APPX_DELAY) {</pre>
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      while (sDirectives.fHost == 0) {
                                    ^{\prime}/ II: send high half of cost table and sync state
                                                                                                                                              _wrapAndSend(ct_report_1(sync_report(NULL)));
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                // enforce minimum delay
                                                                                                                                                                                                                                                                                                                                                                                                           sDirectives.fDelayTics = MIN_APPX_DELAY;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           os_wait2(K_TMO, rand());
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // before starting the appx process, choose a random delay // to cut down on collisions
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        os_wait2(K_SIG, 0);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // reset cost table except to host
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // reset sync statistics
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // reset packet statistics
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                Each tic is
```

```
_bide(sDirectives.fDelayTics);

// III: send packet statistics and ADC values
_wrapAndSend(stats_report(adc_report(NULL)));
_bide(sDirectives.fDelayTics);
}
```

File: arbor.h

```
#ifndef ARBOR_H
#define ARBOR_H
                                                                                          #define OS_TICS_PER_SECOND
                                                                                                                                                                                                                                                                                  #define BITMASK(b7,b6,b5,b4,b3,b2,b1,b0) \
                                                                                                                                                                                                                                                                                                                                                                                                                                                                      typedef unsigned char seq_t;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // pervasive data types
// system-wide definitions
                                                                                                                                                                                                                                                                                                                                                                            // too handy not to define
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     typedef unsigned char cost_t;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    typedef unsigned char node_id;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       #define NULL (void *)0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           #ifndef NULL
                                                                                                                                         // units for os_wait(), assuming 12Mhz clock
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     or adapted as the basis of a commercial software or hardware
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 warranty.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      product without first obtaining appropriate licenses from MIT. MIT makes no representations about the suitability of this software for
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                to distribution in whole or in part, specific prior permission must be obtained from MIT. These programs shall not be used, rewritten,
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              Description: General system definitions for ArborNet nodes
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            any purpose.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              software, in original or modified form, including but not limited
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             copyright notice must be included.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            separated from this distribution directory structure, this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           copies and supporting documentation. If individual files are
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           copyright notice and the original authors' names appear on all
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             purposes only and without fee is hereby granted, provided that this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         software and its documentation for educational and research
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               Media Laboratory, MIT. Permission to use, copy, or modify this
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         For general public use.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           endorsement should be inferred.
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                                                                                                                                                                                                                              \left( \; (b7 << 7) \; \middle| \; (b6 << 6) \; \middle| \; (b5 << 5) \; \middle| \; (b4 << 4) \; \middle| \; (b3 << 3) \; \middle| \; (b2 << 2) \; \middle| \; (b1 << 1) \; \middle| \; (b0) \; \right)
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```

11

```
#define MAIN_TASK 0
#define RADR_TASK 1 // radio receive thread
#define MAC_TASK 2 // radio transmit thread
#define SYNC_TASK 2 // periodic ping thread
#define APPR_TASK 4 // packet receiver task
#define ARQ_TASK 5 // retry packets until ack'd
#define APPX_TASK 6 // send data to collection point
#endif // ARBOR_H
```

File: arbor.c

```
#include "constell.h"
   #include
                                                                           #include "arq.h"
                                                                                                                      #include
                                                                                                                                                          #include
                                                                                                                                                                                                                                          #include "arbor.h'
                                                                                                                                                                                                                                                                                                                     // Main startup file for arbor system
                                                                                                                                                                                                                                                                                                                                                                                                     // warranty.
                                                                                                                                                                                                                                                                                                                                                                                                                                         // any purpose.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // -*- Mode: C++ -*-
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // Description: initialization and main process loop for ArborNet
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  Media Laboratory, MIT. Permission to use, copy, or modify this software and its documentation for educational and research
                                                                                                                                                                                                                                                                                                                                                                                                                                                                         product without first obtaining appropriate licenses from MIT. MIT makes no representations about the suitability of this software for
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            or adapted as the basis of a commercial software or hardware
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           purposes only and without fee is hereby granted, provided that this copyright notice and the original authors' names appear on all copies and supporting documentation. If individual files are
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 For general public use.
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                Advanced Research Projects Agency, Grant No. MOA972-99-1-0012.
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        to distribution in whole or in part, specific prior permission must
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            copyright notice must be included. For any other uses of this software, in original or modified form, including but not limited
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               separated from this distribution directory structure, this
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  File:
   "costTable.h"
                                                                                                               "appx.h"
                                                                                                                                                              "adc.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              arbor.c
                                                                                                                                                                                                                                                                                                                                                                                                                                         It is provided "as is" without express or implied
// adc_init()
// appx_startReporting()
// arq_init()
// for LEDs
// for LEDs
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              All
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   The
```

```
static void _blast_packets() {
  os_delete_task(SYNC_TASK);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              #include <rtx51tny.h>
#include <stdio.h>
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                void test_leds() {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              #include <stdlib.h>
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   #include <aduc824.h>
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       #include
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      #include
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           #include
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   #include
// program entry point here
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      // 9.4 mSec. tics must be less than 256.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         #define BIDE(tics) os_wait2(K_TMO, (tics))
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         #include
                                   // Used for debugging.
                                                                                                                                                                                                                                                                                                  // Install {\sf jumper\_0} to {\sf blast} {\sf packets} {\sf directly} to the radio.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     // sleep for the given number of tics.
                                                                                                                                                                                                                                                                                                                                                   LED_OFF(YELLOW_LED);
                                                                                                                                                                                                                          while (JUMPER_0()) {
                                                                                         os_create_task(SYNC_TASK);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                int i;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         for (i=0; i<2; i++) {
                     pkt_t xdata *pkt = adc_report(NULL);
rad_xmitPkt(pkt);
                                                                                                                             os_wait2(K_TMO, 20);
                                                                                                                                                 pkt_free(pkt);
                                                                                                                                                                                                                                                                                                                                                                                              BIDE (20);
                                                                                                                                                                                                                                                                                                                                                                                                           LED_ON (YELLOW_LED);
LED_OFF (GREEN_LED);
                                                                                                                                                                                                                                                                                                                                                                                                                                                     BIDE (20)
                                                                                                                                                                                                       // blast packets
                                                                                                                                                                                                                                                                                                                                                                                                                                                                 LED_OFF(ORANGE_LED);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     LED_ON (GREEN_LED);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        BIDE(20);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         LED_OFF (RED_LED);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            LED_ON (ORANGE_LED) ;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                BIDE (20);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             LED_OFF(AMBER_LED);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   LED_ON (RED_LED);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        BIDE(20);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     LED_OFF(YELLOW_LED);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        LED_ON (AMBER_LED);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  "serial.h"
"stats.h"
"sync.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               "pkt.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          "screen.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              "rad.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   "id.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    "grad.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // puts()
// srand(
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // for os_wait()...
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // grad_init()
// nodeName().
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           srand()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    sync_getLocalTime()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   stats_reset()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       serial_init()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            rad_init()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             pkt_init()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  nodeName()...
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   for PLLCON
                                                                                           // restart sync task
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       Each tic is approximately
```

```
void init() _task_ MAIN_TASK {
   // experiment to see if setting radio pins early makes a difference...
   TR1000_CTL_DIRECTION = BITMASK(0,0,0,0,1,1,0); // setup mode ctl pins
   TR1000_CTL_DRIVE = 0x00; // standard CMOS I/O
   TR1000_CTL0 = 1; // set TR1000 to receive mode
                                                                                                                                                                                                                                                                                                                                                                                                                                                 os_create_task(MAC_TASK);
os_create_task(APPR_TASK);
os_create_task(APPX_TASK);
os_create_task(ARQ_TASK);
                                                                                                                                                                                                                                                                                                                                                                 os_create_task(RADR_TASK);
                                                                                                                                                                                                                                                                                                                                                                                             os_create_task(SYNC_TASK);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         TR1000\_CTL1 = 1;
                                                                                                                                                                                                                                                                                                           SCREEN_CLEAR();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   stats_reset();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  rad_init();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           grad_init();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          ct_init();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   printf("\r\n\r\narbor x0.10 %s\r\n", nodeName());
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               BIDE(10);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         pkt_init();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             test leds();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    PLICON = 0 \times 00; // 12 MHz
                                                                                                                                                                                                                                                       while (1)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            LED_OFF (AMBER_LED);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    adc_init();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          LED_ON(AMBER_LED);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      serial_init();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            srand(nodeID());
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  LED_INIT();
                                                                                                                                                                                                                                                                                                                                                                                                                       // MAC_TASK must be started before SYNC_TASK
                       // This should give a visual indication of synchronization among
                                                   // yellow LED whenever the local clock crosses a 2 second boundary.
                                                                               // typed on the serial input. While it's waiting, it flashes the
                                                                                                         // This loop does two things: It breaks when a character has been
                                                                                                                                                               SCREEN_TASK(("%s command: ", nodeName()));
                                                                                                                                                                                                                        unsigned char prevRTC, tmp;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   TIMECON = 0x13;
nodes.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        x0xxxxxx - count hours 0 to 255 xx01xxxx - count in seconds
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                configure TIMECON to:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 xxxxx0xx - clear TIC interrupt flag
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           xxxx0xxx - auto reload TIC
                                                                                                                                                                                                                                                                                                                                                                    // restart receiver
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // start mac process
// app receive threa
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // initialize analog module
// init cost tables
// init gradient routing module
// init radio module
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // set up baud rate
// init packet storage
                                                                                                                                                                                                                                                                                                                                                                                                // start sync task.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       app receive thread
```

```
prevRTC = sync_getLocalTime();
                                                                                                                                                                                                            tmp = getchar();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 while (!serial_charIsAvailable()) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                // to an unsigned char, or 256 tics, or two seconds.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // Note that sync_getLocalTime() returns time in units of 128ths
// of a second. When assigned to prevRTC and tmp, it's truncated
                                                                                                                                                                                                                                     // here when a serial char became available
                         appx_stopReporting();
else {
putchar('?');
                                                                            appx_startReporting(nodeID());
else if (tmp == 'S') {
  printf("...stop reporting");
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         prevRTC = tmp;
                                                                                                                                                         printf("...start reporting");
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     } else {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  if (JUMPER_0()) _blast_packets();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // blast packets if jumper 0 installed
                                                                                                                                                                                (tmp == 'H') {
                                                                                                                                                                                                                                                                                                                                                                // os_wait2(K_TMO, ((256-tmp)>>1)+10);
                                                                                                                                                                                                                                                                                                                                                                                            os_wait2(K_TMO, (256-tmp)>>1);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         } else
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              LED_OFF (YELLOW_LED);
                                                                                                                                                                                                                                                                                                                                                                                                                 // checking again.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // We expect tmp to roll over in 256 - tmp RTC tics, so
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // One RTC tic is 7.8125 mSec. One OS tic is 9.44 tics
                                                                                                                                                                                                                                                                                                                                                                                                                                           // we conservatively wait (256-tmp)/2 OS tics before
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           os_wait2(K_TMO, 1);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // blip otherwise
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // also truncated...
// virtual RTC rolled over
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // truncated to 2 seconds
```

File: arq.h

```
// effectively prevents the ARQ system from ever sending repeat packets.
// The number of ARQ (requests) issued and the number of ACK (replies)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // segments with SEG_TYPE_ARQ or SEG_TYPE_ACK have this
                                                                                                                                                                                                                                                                                  // BIG OL' NOTE: The ARQ_DETAULT_RETRIES has been set to zero, which
                                                                                                                                                                                                                                                                                                                                                                            // a little debugging info.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          #include "pkt.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         #define ARQ_H
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    #ifndef ARQ_H
                                                                                                                                                                                                                                                                                                                                                                                                                       // artifacts that simplify the programming and offer
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       ^\prime/ Copyright 2001 by the Massachusetts Institute of Technology.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         / File:
                                                                                                                                         are logged in the statistics, though.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    as their payload.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             the message.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        an originator that wants a reply installs an arq segment in
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       product without first obtaining appropriate licenses from MIT. makes no representations about the suitability of this software any purpose. It is provided "as is" without express or implied
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        or adapted as the basis of a commercial software or hardware
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      copies and supporting documentation. If individual files are
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               Media Laboratory, MIT.
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             Description: Header file for Automatic Reply reQuest mechanism
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       be obtained from MIT.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      software,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 copyright notice must be included.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           separated from this distribution directory structure, this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                purposes only and without fee is hereby granted, provided that this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        software and its documentation for educational and research
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        For general public use
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     position or the policy of the Government, and no official
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           This MIT Media Laboratory project was sponsored by the Defense Advanced Research Projects Agency, Grant No. MOA972-99-1-0012.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          -*- Mode: C++ -*-
testing, we don't want the variability introduced by repeated ARQ
                                               This is because the ARQ/ACK sytem has been shown to work, but
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     ids are assumed to be available in a grad seg in the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  to distribution in whole or in part, specific prior permission must
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          copyright notice and the original authors' names appear on all
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          endorsement should be inferred.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    content of the information does not necessarily reflect the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            rights reserved
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 in original or modified form, including but not limited
                                                                                                                                                                                                                                                                                                                                                                                                                                                                              the fTimeout and fRetries fields are
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             The receiver will send an ack packet in reply.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        The originator and destination
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   These programs shall not be used, rewritten,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               Permission to use, copy, or modify this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 For any other uses of this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            All
                                               for
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   The
```

```
void arq_didXmit(pkt_t xdata *pkt);
// Called by the MAC thread when a packet is sent. If the packet
                                                                                                                                                                                                                                                                                                                                                                                                           void arq\_serviceAck(pkt\_t xdata *seg); // Handle an incoming ACK packet. Respond by finding and deleting the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                pkt_t xdata *arq_makeArq(pkt_t xdata *pkt);
// install SEG_TYPE_ARQ segment in pkt
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              } ackPayload;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       typedef struct _arqPayload unsigned char fReference;
                   // Task regularly examines retry queue. If there is a packet in the
// retry queue, remove it from the queue and pass it to the MAC layer
                                                                                                                                                                  // queue.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               pkt_t xdata *arq_makeAck(pkt_t xdata *pkt, unsigned char reference);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // ARQ quits re-sending a packet after RETRIES attempts
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         #define ARQ_DEFAULT_RETRIES 0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // packets -- we'd rather just drop the packet than retry.
                                                                                              // void arq_task(void) _task_ ARQ_TASK
                                                                                                                                                                                                                                                                                                                                                                                     // corresponding packet in the retry queue
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // sending it to the originator.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       void arq_serviceArq(pkt_t xdata *seg, pkt_t xdata *grad);
                                                                                                                                                                                                            // create a copy of the packet and install the copy in the retry
                                                                                                                                                                                                                                            // contains an ARQ header and its retry count is greater than 0,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // install SEG_TYPE_ACK segment in pkt
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // Handle an incoming ARQ packet.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       arqPayload;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    unsigned char fRetries;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  unsigned char
for transmission.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  fReference;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  ackPayload
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       fReference;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // packet ID
// # of times
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    Respond by creating an
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          remaining
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    ACK packet and
```

#endif

File: arq.c

```
// -*- Mode: C++ -*-
// File: arq.c
// Description: Automatic Reply reQuest: manage ARQ and ACK packets
// Description: Automatic Reply reQuest: manage ARQ and ACK packets
// Copyright 2001 by the Massachusetts Institute of Technology. All
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// This MIT Media Laboratory project was sponsored by the Defense
// Advanced Research Projects Agency, Grant No. MOA972-99-1-0012. The
// content of the information does not necessarily reflect the
// position or the policy of the Government, and no official
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```
#define ARQ_INTERVAL_TICS OS_TICS_PER_SECOND
// Once every ARQ_INTERVAL_TICS, examine the retry queue. If there
// is a packet available, remove it and pass it to the MAC layer for
                                                                                                                                                             pkt_t xdata *arq_makeArq(pkt_t xdata *pkt) {
   // add an arq segment to this packet
                                                                                                                                                                                                                                                                                                                                                                                                                                   static unsigned char gReference;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   DEFINE_VECTOR(gRetryQueue, RETRY_QUEUE_SIZE);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     // from a remote host.
#define RETRY_QUEUE_SIZE 4
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           #include <stdio.h>
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            #include
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             #include
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               #include
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // warranty.
                                                                                                                                                                                                                                                                                                                                                                                                    // A reference number for each ACK packet generated
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // retransmission.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                #include
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 #include
                                                                                                                                                                                                                                                                        // public routines
                                                                                                                                                                                                                                                                                                                                        // The gRetryQueue is the home
                                                                                                                                                                                                                                                                                                      argPayload xdata *ap = pkt_payload(argSeg);
                                                                                                                                  pkt_t xdata *arqSeg = pkt_alloc();
ap->fRetries = ARQ_DEFAULT_RETRIES;
                                 ap->fReference = gReference++;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                be obtained from MIT. These programs shall not be used, rewritten, or adapted as the basis of a commercial software or hardware
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 makes no representations about the suitability of this software for
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     software,
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      <rtx51tny.h>
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             "vector.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         "stats.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             "screen.h'
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            "pkt.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             "mac.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              "id.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                "grad.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              "arq.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                "arbor.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              "appr.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               notice must be included. For any other uses of this in original or modified form, including but not limited
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               It is provided "as is" without express or implied
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         This limits the maximum rate of retries.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // for os_wait()...
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     for packets awaiting an ACK
```

```
void arq_serviceAck(pkt_t xdata *seg) {
   // seg is known to be SEG_TYPE_ACK, and part of a packet targeted
   // for this node. If it is an acknowlegement for an ARQ packet
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         pkt_t xdata *arq_makeAck(pkt_t xdata *pkt, unsigned char reference) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   void arq_serviceArq(pkt_t xdata *seg, pkt_t xdata *grad) {
   // Handle an incoming ARQ packet. Respond by creating an ACK packet
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   >fOriginator));
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         gp = (gradPayload xdata *)pkt_payload(grad);
ap = (arqPayload xdata *)pkt_payload(seg);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     return ackSeg;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     pkt_size(ackSeg)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         pkt_t xdata *ackSeg = pkt_payload(ackSeg);
ackPayload xdata *ap = pkt_payload(ackSeg);
                                                                                                                                                                                                                             while (i--) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // ## don't call before ARQ_TASK is started
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                //\ {
m festering} in the retry queue, now is the time to delete it
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       if (grad == NULL)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    arqPayload xdata *ap;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          gradPayload xdata *gp;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             stats_arq();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 pkt_next(arqSeg) = pkt;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            pkt_type(arqSeg) = SEG_TYPE_ARQ;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 pkt_size(arqSeg) = sizeof(arqPayload);
                                                                                                                                                                                                                                                                                                 stats_ack();
                                                                                                                                                                                                                                                                                                                                                                               unsigned char i = VECTOR(gRetryQueue)->fCount;
                                                                                                                                                                                                                                                                                                                                                                                                                     ackPayload xdata *ackh = pkt_payload(seg);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     mac_xmitPkt(grad_makePkt(arq_makeAck(NULL, ap->fReference),gp-
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // can't handle a packet with no return address
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // type SEG_TYPE_ARQ, grad (if non null) is SEG_TYPE_GRAD.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // and sending it to the originator. seg is known to be a segment of
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        pkt_next(ackSeg) = pkt;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          pkt_type(ackSeg) = SEG_TYPE_ACK;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // add an ack segment to packet
                                                                          arqSeg = pkt_find_segment(retryPkt, SEG_TYPE_ARQ);
                                                                                                                retryPkt = fast_vector_ref(VECTOR(gRetryQueue),
                                                                                                                                                     pkt_t xdata *arqSeg;
                                                                                                                                                                                           pkt_t xdata *retryPkt;
                                        if (arqSeg != NULL) {
arqPayload xdata *arqh = pkt_payload(arqSeg);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   = sizeof(ackPayload);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        reference;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           return;
                                                                                                                                                                                                                                                                                                    // log an acknowlegement received
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                // log a request for acknowlegement
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // link to main packet
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // link to main packet
```

```
void arq_task(void) _task_ ARQ_TASK {    // Task regularly examines the retry queue, passing messages to the    // MAC layer for retransmission as they become available.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               void arq_didXmit(pkt_t xdata *pkt) {
   // Called by the MAC thread when a packet is sent. If this node
   // is the originator and it has an ARQ header and its retry count
   // is greater than 0, create a copy of the packet and install it
   // in the retry queue.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             nodeID())) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   if ((arqSeg = pkt_find_segment(pkt, SEG_TYPE_ARQ)) == NULL) {
   // no ARQ segment in the packet - fuggeddaboudit
                                                                                                                                                                                                          gReference = 0;
                                                                                                                                                                                                                                                                                                                            pkt_t xdata *pkt;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          arqPayload xdata *ap;
                                                                                                                                                                                                                                    vector_init(VECTOR(gRetryQueue), RETRY_QUEUE_SIZE);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     if (((gradSeg = grad_find_segment(pkt)) == NULL) | |
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       pkt_t xdata *gradSeg;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    pkt_t xdata *arqSeg;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // ## don't call before ARQ_TASK is started
                                                                                                                                                    while (1) {
                                                                                                                                                                                                                                                                       // one time initialization
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           return;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                // we weren't the originator
  (((gradPayload xdata *)pkt_payload(gradSeg))->fOriginator !=
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      if (argh->fReference == ackh->fReference) {
   // found a match. Remove retryPkt from the retry queue.
                                                          // Block until there might be a packet in the retry queue
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         pkt_free(fast_vector_remove(VECTOR(gRetryQueue), i));
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   return;
// arq_didXmit() will generate signal
```

```
}
// This wait() regulates the max rate at which retries are sent
os_wait2(K_TMO, ARQ_INTERVAL_TICS);
// the packet may have been removed by serviceAck() while we were
// waiting. Check if the packet is still there before continuing.
} while ((pkt = vector_dequeue(VECTOR(gRetryQueue))) == NULL);
// pkt is the packet to be retransmitted. Update grad info
// and pass ot MAC layer for retransmission
grad_updateSeg(pkt);
mac_xmitPkt(pkt);
mac_xmitPkt(pkt);
SCREEN_TASK(("arq_task(3) %bu", vector_count(VECTOR(gRetryQueue))));
```

File: constell.h

char byte;

```
#ifndef _CONSTELL_H_
typedef union
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   #define
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   typedef struct
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           #define PSD_REG_BASE
                                   // union allowing either byte or bit access to 8-bit register
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // general structure of 8-bit register allowing bit access
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // For general public use.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      // File:
                                                                                                                Register;
                                                                                                                                               unsigned char bit1 : 1;
unsigned char bit2 : 1;
unsigned char bit4 : 1;
unsigned char bit4 : 1;
unsigned char bit5 : 1;
unsigned char bit6 : 1;
unsigned char bit7 : 1;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        Media Laboratory, MIT.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            Copyright 2001 by the Massachusetts Institute of Technology.
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                efine _CONSTELL_H_
-*- Mode: C++ -*-
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                makes no representations about the suitability of this software for any purpose. It is provided "as is" without express or implied
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              This distribution is approved by Walter Bender, Director of the
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            endorsement should be inferred.
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         rights reserved
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             Author:
                                                                                                                                                                                                                                                                                                                                                                                                                             unsigned char bit0
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```
#define DATAIN_D
#define DATAOUT_A
#define DATAOUT_B
#define DATAOUT_C
#define DATAOUT_D
                                                                                                                                                                                                                                 #define
                                                                                                                                                                                                                                               #define
                                                                                                                                                                                                                                                              #define
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                                                                                                                                                                                                                                                                                                          #define
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                                                                                                                                                                                                                                                                                                                                                                    #define OUTENABLE_B
#define OUTENABLE_C
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            #define DIRECTION_B
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   #define DATAIN_
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                                               #define
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                                                                                                                                                                                                                                                                                                                                                                                                                                #define DRIVE
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                                                                                                                                                                                                              OMCMASK_AB
                                                                                                                                                                                                                                           IMC_B

OMC_AB

OMC_BC
                              PA2
                                                                                                         M
                                                                                                                                       PMMR2
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                                                                                                                                                                                   ALTPROTECT
                                                                                                                                                                                                 MAINPROTECT
                                                                                                                                                                                                                                                                                                          IMC_A
                                                                                                                                                                                                                                                                                                                      CONTROL_B
                                                                                                                                                                                                                                                                                                                                       CONTROL_A
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*) (PSD_REG_BASE+0x01))
                                                                                                                                                      *) (PSD_REG_BASE+0xB0)
                                                                                                                                                                    *) (PSD_REG_
                                                                                                                                                                                                                                                                                                                         *) (PSD_REG_BASE+0x03)
                                                                                                                                                                                                                                                                                                                                       *) (PSD_REG_BASE+0x02)
                                                                                                                                                                                                                                                                                                                                                      *)(PSD_REG_BASE+0x1B)
                                                                                                                                                                                                                                                                                                                                                                                     *) (PSD_REG_BASE+0x0D)
                                                                                                                                                                                                                                                                                                                                                                                                    *) (PSD_REG_BASE+0x0C)
                                                                                                                                                                                                                                                                                                                                                                                                                   *)(PSD REG BASE+0x17)
                                                                                                                                                                                                                                                                                                                                                                                                                                 *) (PSD_REG_BASE+0x16)
                                                                                                                                                                                                                                                                                                                                                                                                                                                 *) (PSD_REG_BASE+0x09)
                                                                                                                                                                                                                                                                                                                                                                                                                                                               *) (PSD_REG_BASE+0x08)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                              *) (PSD_REG_BASE+0x15)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             *) (PSD_REG_BASE+0x14))
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             *)(PSD REG BASE+0x07))
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          *) (PSD_REG_BASE+0x06))
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  *) (PSD_REG_BASE+0x10))
                                                                                                         (PSD_REG_BASE+0xE2)
                                                                                                                                                                                   (PSD_REG_
                                                                                                                                                                                                 (PSD_REG_
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                                                                                                                                                                                                                              (PSD_REG_BASE+0x22)
                                                                                                                                                                                                                                              (PSD_REG_BASE+0x21)
                                                                                                                                                                                                                                                             (PSD_REG_
                                                                                                                                                                                                                                                                           (PSD_REG_BASE+0x18)
                                                                                                                                                                                                                                                                                          (PSD_REG_BASE+0x0B)
                                                                                                                                                                                                                                                                                                          (PSD_REG_BASE+0x0A)
                                                                                                                                                                                   BASE+0xC2)
                                                                                                                                                                                                  BASE+0xC0)
                                                                                                                                                                                                                                                             BASE+0x20)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          BASE+0x13))
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         BASE+0x12))
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        BASE+0x05))
                                                                                                                                                                     BASE+0xC7)
                                                                                                                                                                                                                  BASE+0x23)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      BASE+0x04))
```

#define #define #define

PB1 PB0

bito bit1 bit2

#define PA7 #define #define #define #define

PA4

PA5 PA3

bit5

//PSD PORTB

#define PB3

```
#define PC0
#define PC1
#define PC2
#define PC3
#define PC4
#define PC5
#define PC6
                                                                                                                                                                                                                                                                                                                                                                    #define PLD_ALE #define PLD_DBE
#define TR1000_CTL0
                                // sfr PLLCON = 0xD7;
                                                                                             #define MAX_EEPROM_RETRY 0x0FFF
                                                                                                                                                                                                         // Flash parameters
                                                                                                                                                                                                                                                        #define EE_DATA
#define FL_DATA
                                                                                                                                                                                                                                                                                        #define EE_CODE
#define FL_CODE
                                                                                                                                                                                                                                                                                                                                                                                                                                    #define PLD_CNTLO
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          #define PB7
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          #define
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          #define
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       #define
                                                              // a write opertaion to EEPROM
                                                                                                              // For F2 with EEPROM boot
                                                                                                                                          #define NVM_ERROR
                                                                                                                                                          #define NVM_DATA_TOGGLE
                                                                                                                                                                         #define NVM_DATA_POLL
                                                                                                                                                                                                                                         #define PIO_EN
                                                                                                                                                                                                                                                                                                                        #define SRAM_CODE
                                                                                                                                                                                                                                                                                                                                                                                                  #define PLD_CNTL2
                                                                                                                                                                                                                                                                                                                                                                                                                    #define PLD_CNTL1
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   #define PLD_MCELL_CLK
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   #define PLD_ARRAY_CLK
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   #define PLD_TURBO
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   #define APD_ENABLE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                #define JEN
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                #define PD2
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             #define PD0
                                                                             // Maximum number of attemps to check status after
                                                                                                                                                                                                                                                                                                                                        //PSD VM
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   //PSD PMMRO
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               #define PD1
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        //PSD PORTC
                                                                                                                                                                                                                                                                                                                                                                                                                                                    //PSD PMMR2
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                //PSD JTAG
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               //PSD PORTD
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       PB4
PB5
PB6
                                                                                                                                                         0x80
0x40
                                                                                                                                                                                                                                                                                                                                                                       bit2
bit3
bit4
bit5
bit6
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   bit4
bit5
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   bit1
bit3
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           bit0
bit1
bit2
bit3
bit4
bit4
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       bit6
                                                                                                                                                                                                                                                                                         bit2
                                                                                                                                                                                                                                                                                                         bit1
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                bit1
bit2
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       bit4
bit5
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   bito
DATAOUT_D->bits.PD1
                                                                                                                                          // flash status "data poll" bit at DQ7
// flash status "toggle poll" bit at DQ6
// flash status "error" bit at DQ5
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                // JTAG enable
                                                                                                                                                                                                                                                                         #define ORANGE_LED #define GREEN_LED
                                                                                                                                                                                                                                                                                                                                                  #define LED_OFF(b)
#define ALL_LEDS_ON()
#define ALL_LEDS_OFF()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            #define LED_SET
#define BART_READY
#define BART_CLOCK
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      #define BART_DATA_CONTROL
#define BART_DATA_OUT
#define BART_DATA_IN
#define LED_DIRECTION
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       #define TR1000_CTL1 DATA(
#define TR1000_CTL_DIRECTION DIRECTION_D->byte
#define TR1000_CTL_DRIVE DRIVE_D->byte
                                                                                                                                                            #endif // CONSTELL_H
                                                                                                                                                                                         #define JUMPER_1()
                                                                                                                                                                                                                                                                                                                                                                                                                                 // To turn LED on, pull pin down to ground because other end is connected to // Vcc. To turn LED off, pull pin up.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   #define RECV 0x00
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               #define BART_MODE_XMIT 0
#define BART_MODE_RECV 1
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     #define BART_DATA_DIRECTION DIRECTION_B->byte #define BART_DATA_DRIVE DRIVE_B->byte
                                                                                                                                                                                                         #define JUMPER_0()
                                                                                                                                                                                                                                                        #define YELLOW_LED
                                                                                                                                                                                                                                                                                                         #define RED_LED
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                #define LED_INIT() LED_DIRECTION = 0x1F; \
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 #define XMIT 0xFF
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             #define BART_MODE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              #define
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            #define
                                                                                                                                                                                                                                                                                                                        #define AMBER_LED
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                // values for xxx_DIRECTION registers
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // values for BART_MODE
                                                                                                                                                                                                                          // return true when
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           LED_DRIVE
LED_CONTROL
                                                                                                                                                                                                                                                                                                                                                                                                     LED_ON(b)
                                                                                                                                                                                                                                                                                                      PA0
PA1
                                                                                                                                                                                                                         jumper installed
                                                                                                                                                                                                                                                                         PA3
                                                                                                                                                                                                                                                                                        PA2
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 LED_SET->byte = 0xFF
                                                                                                                                                                                                                                                                                                                                                            LED_SET->bits.b = 0
LED_SET->byte = 0x00
                                                                                                                                                                                                                                                                                                                                                    LED_SET->byte =
                                                                                                                                                                                          (!DATAIN_C->bits.PC7)
                                                                                                                                                                                                            (!DATAIN_C->bits.PC2)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               TO
T1
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             OLNI
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           DATAOUT_A
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           CONTROL_A->byte
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           DRIVE_A->byte
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         DIRECTION_A->byte
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        DATAOUT_B->byte
DATAIN_B->byte
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        CONTROL_B->byte
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   LED_CONTROL
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   LED_DRIVE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       DATAOUT_D->bits.PD2
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    \Pi = \Pi
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    0x00;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 0x00;
```

File: costTable.h

```
#ifndef COST_TABLE_H
#define COST_TABLE_H
                                                                                                                            typedef struct
                                                                                                                                                                                                        // costRecord structure isn't really required.
                                                                                                                                                                                                                                                                                                                                                                     // to node.
                                                                                                                                                                                                                                                                                                                                                                                                                                              // A costRecord represents this node's cost to a given originator. A
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              #define COST_UNKNOWN ((cost_t)0xff)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      #include
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          #include
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  #include
                                                                                                                                                                                                                                                                                        // ## NB: Since the cost table is now layed out with the N'th entry
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // -*- Mode: C++ -*-
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // Media Laboratory, MIT. Permission to use, copy, or modify this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // This distribution is approved by Walter Bender, Director of the
                                        node_id fOriginator;
seq_t fSequence;
       cost_t fCost;
                                                                                                                                                                                                                                                corresponding to fOriginator == N, the fOriginator field in the
                                                                                                                                                                                                                                                                                                                                                                                                         message leaves behind a trial of costRecords as it hops from node
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 product without first obtaining appropriate licenses from MIT. MIT makes no representations about the suitability of this software for any purpose. It is provided "as is" without express or implied
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         or adapted as the basis of a commercial software or hardware
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      copyright notice must be included.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 For general public use.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             This MIT Media Laboratory project was sponsored by the Defense Advanced Research Projects Agency, Grant No. MOA972-99-1-0012. content of the information does not necessarily reflect the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               Description: header file for cost table routines
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 be obtained from MIT.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              software, in original or modified form, including but not limited
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              separated from this distribution directory structure, this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            purposes only and without fee is hereby granted, provided that this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           software and its documentation for educational and research
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               Copyright 2001 by the Massachusetts Institute of Technology.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      to distribution in whole or in part, specific prior permission must
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      copies and supporting documentation. If individual files are
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              copyright notice and the original authors' names appear on all
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    endorsement should be inferred.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         position or the policy of the Government, and no official
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              rights reserved.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           File:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              "pkt.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   "grad.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               "arbor.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           costTable.h
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // for gradPayload
// for pkt_t do
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              These programs shall not be used, rewritten,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              for pkt_t def
// originator of this costRecord
// orignator's sequence number
// accrued cost since origination
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  For any other uses of this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      All
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         The
```

```
pkt_t xdata *ct_report_1(pkt_t xdata *next);
pkt_t xdata *ct_report_h(pkt_t xdata *next);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 bit ct_shouldRelay(gradPayload xdata *gh, bit isDiscovery);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         } costRecord;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  #endif
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 cost_t ct_costTo(node_id node);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // the given budget. Otherwise return false.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                // message is stale, the hops field is updated if the new record is // advantageous.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  bit ct_update(gradPayload xdata *gh);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            void ct_reset_except (node_id target);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // initialize the cost table
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // Support for costRecords
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // costRecord in the routing table.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // originator/sequence pair corresponds to fresh message.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // reset all entries in the cost table except for
// target. If target is out of range, resets all
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            void ct_init();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // return packets with low half and high half of routing table
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // Return the cost to the given node, or COST_UNKNOWN if there is no
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // exist, return true if the cost table's hop count is smaller than
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // for the destination doesn't exist, return false.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // Look up the cost for destination in the routing table.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               File: costTable.c
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         Create or update a costRecord for originator, returning true if
                                 This MIT Media Laboratory project was sponsored by the Defense
                                                                                                                        rights reserved.
                                                                                                                                                                 Copyright 2001 by the Massachusetts Institute of Technology.
                                                                                                                                                                                                                                                    Description: maintain cost estimates to other nodes
                                                                                                                                                                                                                                                                                                                                                                            -*- Mode: C++ -*-
Advanced Research Projects Agency, Grant No. MOA972-99-1-0012.
                                                                                                                                                                                                                                                                                             costTable.c
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      If a record does
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       Even if the
                                                                                                                                                                     All
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purposes only and without fee is hereby granted, provided that this
                                                           software and its documentation for educational and research
                                                                                                            Media Laboratory, MIT. Permission to use, copy, or modify this
                                                                                                                                                                                                                                                                                                     For general public use.
                                                                                                                                                                             This distribution is approved by Walter Bender, Director of the
                                                                                                                                                                                                                                                                                                                                                                                                                            endorsement should be inferred.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   position or the policy of the Government, and no official
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              content of the information does not necessarily reflect the
```

```
static int _recordIndex(node_id originator) {
   // map a node id to a cost table index, returning -1 if the
   // node id is out of range.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         #include "id.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // copyright notice and the original authors' names appear on all copies and supporting documentation. If individual files are
                                                                                     static void
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                #define NULL_ORIGINATOR (node_id)0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      static void
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           static int _findRecord(node_id originator);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      // internal procedures
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          static costRecord xdata _costRecords[MAX_COSTRECORDS];
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         #define MIN_ID 'A'
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                #define COST_REPORT_SIZE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          #define MAX_COSTRECORDS
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // the actual storage for vector and costRecords
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   #include <stdio.h>
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              #include "costTable.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // Modified fancy LRU cost table to direcly indexed one node/one entry // form. This is simple and fast, but not scalable.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // 08Nov2000 r@media.mit.edu
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // Support for cost tables
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // IDs are biased by this offset
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // allocate a static pool of cost records
                                                                                                                                                                                                                                                                                                                                                               if ((originator < MIN_ID) || (originator >= (MIN_ID + MAX_COSTRECORDS))) {
unsigned char index = _recordIndex(gp->fOriginator);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            product without first obtaining appropriate licenses from MIT. MIT makes no representations about the suitability of this software for any purpose. It is provided "as is" without express or implied
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           be obtained from MIT. These programs shall not be used, rewritten, or adapted as the basis of a commercial software or hardware
                                         // copy gradPayload's salient points into the cost table.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           copyright notice must be included.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             separated from this distribution directory structure, this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              warranty.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         to distribution in whole or in part, specific prior permission must
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  software, in original or modified form, including but not limited
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       copyright notice and the original authors' names appear on all
                                                                                                                                                                                                                                                  return originator-MIN_ID;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           _createRecord(gradPayload xdata *gp);
                                                                                  _createRecord(gradPayload xdata *gp) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                26
13
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           For any other uses of this
   if (IS_NEWER(gp->fSequence, cr->fSequence)) {
```

```
#define IS_NEWER(seqA, seqB) ((((seqB)-(seqA)) & OxfO) != 0)
// IS_NEWER() returns true if sequence number A is newer than sequence
// number B, in this case, within 16 counts. A and B are interpreted to
// be MOD 256 (one byte).
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  bit ct update(gradPayload xdata *gp) {
   // Create or update a cost record for originator, returning true if
   // originator/sequence pair corresponds to fresh message. Even if
   // the message is stale, the cost field is updated if the new record
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                void ct_reset_except(node_id target) {
   // clear cost entry for all nodes except the specified target
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        void ct_init() {
   // initialize the cost table with unused cost records
   ct_reset_except(NULL_ORIGINATOR);
   .
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // exported procedures
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              unsigned char i;
cr = &_costRecords[index];
                                                                                                                                                                                                                                                                                                                                                                                                                                        if (gp->fOriginator == nodeID()) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      unsigned char index;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         for (i=0; i<MAX_COSTRECORDS; i++) {
                                                                                                                                                                                      if (index == -1) {
                                                                                                                                                                                                                                                     index = _recordIndex(gp->fOriginator);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     costRecord xdata *cr;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               if (index != -1) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // is advantageous.
                                                                                                                                                                                                                                                                                                                                                                      return 0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             cr->fCost = gp->fCostAccrued;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              cr->fSequence = gp->fSequence;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      cr->fOriginator = gp->fOriginator;
                                                                                                                return 1;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          costRecord xdata *cr = &_costRecords[index];
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                if (i != _recordIndex(target)) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       costRecord xdata *cr;
                                                                                                                                                                                                                                                                                                                                                                                                       // I was the originator of this message. Feggadaboudit.
                                                                                                                                              _createRecord(gp);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       cr->fOriginator = NULL_ORIGINATOR;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              cr = &_costRecords[i];
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  cr->fCost = COST_UNKNOWN;
```

```
pkt_t xdata *ct_report_1(pkt_t xdata *next) {
   // create a packet with the low half of the routing table in
   // the payload
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  bit ct_shouldRelay(gradPayload xdata *gp, bit isDiscovery) {
   // if not discovery: look up cost to destination in cost table.
   // if unknown, return false.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         static pkt_t xdata *ct_report(seg_type t,
    unsigned char offset,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          cost_t ct_costTo(node_id node) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   int i = _recordIndex(node);
if (i == -1) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          if (myCost == COST_UNKNOWN) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // return true if the message's cost budget is larger than 0
cost_t myCost = (cost_t) ((isDiscovery)?0:ct_costTo(gp->fDestination));
                                                                                                                                                                                                                                                                                                                                                                             pkt_type(pkt) = t;
                                                                                                                                                                                                                                                                                                                                                                                                           unsigned char *p = pkt_payload(pkt);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   return COST_UNKNOWN;
} else {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     if ((gp->fSequence == cr->fSequence) && (gp->fCostAccrued < cr->fCost)) {
   // this sequence number already seen, but adverized cost is better
   // Update cost estimate
   cr->fCost = gp->fCostAccrued;
                                                                                                                                                                     return pkt;
                                                                                                                                                                                                          pkt_next(pkt) = next;
                                                                                                                                                                                                                                                                    for (i=0; i<COST_REPORT_SIZE; i++) {
   *p++ = (_costRecords[i+offset]).fCost;</pre>
                                                                                                                                                                                                                                                                                                                                           pkt_size(pkt) = COST_REPORT_SIZE;
                                                                                                                                                                                                                                                                                                                                                                                                                                             pkt_t xdata *pkt = pkt_alloc();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  unsigned char i;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // record in the routing table.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // Return the cost to the given node, or COST_UNKNOWN if there is no
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                } else {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // if discovery:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  costRecord xdata *cr = &_costRecords[i];
return cr->fCost;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              return (gp->fCostBudget > myCost);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        cr->fSequence = gp->fSequence;
cr->fCost = gp->fCostAccrued;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  return 0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    else return true if the message's cost budget is larger than this node's cost to the destination.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           pkt_t xdata *next) {
```

```
return ct_report(SEG_TYPE_COST_L, 0, next);
}

pkt_t xdata *ct_report h(pkt_t xdata *next) {
    // create a packet with the high half of the routing table in
    // the payload
    return ct_report(SEG_TYPE_COST_H, COST_REPORT_SIZE, next);
}
```

File: grad.h

```
#include "arbor.h"
#define BROADCAST_NODE 0xff
                                                                                                                                                                                                                                                                                                                                                                                         typedef struct _gradPayload {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      #include
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        #define GRAD_H
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               #ifndef GRAD_H
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // A gradPayload contains the information used by the gradient routing
                                              // a node that will never be a target
                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // segment whose type is SEG_TYPE_GRADIENT or SEG_TYPE_DISCOVERY
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                // This distribution is approved by Walter Bender, Director of the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // For general public use
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // mechanism. A gradPayload can be found in the payload of any packet
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // Copyright 2001 by the Massachusetts Institute of Technology.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   / File:
                                                                                                                                gradPayload;
                                                                                                                                                                       unsigned char fCostBudget;
                                                                                                                                                                                                                  node_id fDestination;
                                                                                                                                                                                                                                                            unsigned char fCostAccrued;
                                                                                                                                                                                                                                                                                                       unsigned char fSequence;
                                                                                                                                                                                                                                                                                                                                              node_id fOriginator;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        or adapted as the basis of a commercial software or hardware product without first obtaining appropriate licenses from MIT. MIT makes no representations about the suitability of this software for any purpose. It is provided "as is" without express or implied
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     copies and supporting documentation. If individual files are
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   purposes only and without fee is hereby granted, provided that this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      software and its documentation for educational and research
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         Media Laboratory, MIT.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    This MIT Media Laboratory project was sponsored by the Defense Advanced Research Projects Agency, Grant No. MOA972-99-1-0012.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             Description: header file for gradient routing support
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             -*- Mode: C++ -*
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       be obtained from MIT.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             software,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                copyright notice must be included.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           separated from this distribution directory structure, this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                copyright notice and the original authors' names appear on all
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               endorsement should be inferred.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      position or the policy of the Government, and no official
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        rights reserved
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              to distribution in whole or in part, specific prior permission must
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 content of the information does not necessarily reflect the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  "pkt.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         in original or modified form, including but not limited
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // for pkt_t
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                These programs shall not be used, rewritten,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         Permission to use, copy, or modify this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    For any other uses of this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   All
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       The
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void grad_relayIfNeeded(pkt_t xdata *pkt, pkt_t xdata *gradSeg);
// seg must refer to a packet segment of type SEG_TYPE_DISCOVERY
                                                                                                                                                                                                                                                                                                                                                                                                   bit grad_isForMe(pkt_t xdata *gradSeg);
// seg must refer to a packet segment of type SEG_TYPE_DISCOVERY
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   bit grad_segIsFresh(pkt_t xdata *gradSeg);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  pkt_t xdata *grad_makePkt(pkt_t xdata *pkt, node_id dest);
// install a GRAd segment in this packet.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // ASSERT(sizeof(gradPayload)<MAX_PAYLOAD_SIZE, "gradPkt payload too big");
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         #define DEFAULT_DISCOVERY_COST
#endif
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    void grad_updateSeg(pkt_t xdata *pkt);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        pkt_t xdata *grad_find_segment(pkt_t xdata *pkt);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // intialize the gradient routing system
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // packet.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // find a SEG_TYPE_GRADIENT or SEG_TYPE_DISCOVERY segment in the packet
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                void grad_init();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // find the SEG_TYPE_DISCOVERY or SEG_TYPE_GRADIENT segment in this
                                                                                      // free it.
                                                                                                                                                                                                                                                                                                            // for this node (dest is either {\tt BROADCAST\_NODE} or this node).
                                                                                                                                                                                                                                                                                                                                                                  // or SEG_TYPE_GRADIENT.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // this packet hasn't been seen before.
                                                                                                                                   // or SEG_TYPE_GRADIENT. Relay pkt if appropriate, else just
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // or SEG_TYPE_GRADIENT. Updates cost tables, returns true if
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      // seg must refer to a packet segment of type SEG_TYPE_DISCOVERY
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         In-place, fixup current sequence number and cost info.
                                                                                                                                                                                                                                                                                                                                                                  Returns true if the packet is destined
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 25
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File: grad.c

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File: grad.c

Description: To relay or not to relay? Answered here...

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// GRAd is responsible for the routing of packets. Upon reception,
// GRAd decides whether to relay a packet, pass it to the application
// level, or to drop it. For transmission, GRAd appends a routing
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      pkt_t xdata *grad_find_segment(pkt_t xdata *pkt) {
   // search the list of segments for a packet that contains
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    #include "mac.h"
#include "arq.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          #include "costTable.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            #include "arbor.h"
                                                                                                                                                                                                                                                                                                           static seg_type grad_prepPayload(gradPayload xdata *payload, node_id dest)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          void grad_init() {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // exported routines
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // Sequence number for next originated packet.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  static unsigned char gSequence;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             #include <stdio.h>
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   #include "stats.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          #include "id.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         #include
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // header that will be used by the GRAd service in receiving nodes
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // copies and supporting documentation. If individual files are
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   gSequence = 0;
                                                                                                                  payload->fOriginator = nodeID();
                                                                                                                                                             cost_t cost = ct_costTo(dest);
                                       payload->fCostAccrued = 1;
                                                                          payload->fSequence = gSequence++;
                                                                                                                                                                                                                                                                                                                                                                                                                                        return NULL;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              while (pkt != NULL) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              or adapted as the basis of a commercial software or hardware product without first obtaining appropriate licenses from MIT. MIT makes no representations about the suitability of this software for any purpose. It is provided "as is" without express or implied
payload->fDestination = dest;
                                                                                                                                                                                      // fill in a gradPayload with dest, cost, sequence, etc.
// SEG_TYPE_DISCOVERY or SEG_TYPE_GRADIENT as appropriate
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // gradPayload.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   purposes only and without fee is hereby granted, provided that this copyright notice and the original authors' names appear on all
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           to distribution in whole or in part, specific prior permission must be obtained from MIT. These programs shall not be used, rewritten,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         software, in original or modified form, including but not limited
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     warranty.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                copyright notice must be included.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    separated from this distribution directory structure, this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   seg_type t = pkt_type(pkt);
if ((t == SEG_TYPE_GRADIENT) || (t == SEG_TYPE_DISCOVERY)) return pkt;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                pkt = pkt_next(pkt);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              "grad.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // ct_costTo() ...
// nodeID()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // arq_recvPkt()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // stats_origPkt()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // mac_xmitPkt()...
                                       // receivers are already one hop away
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                For any other uses of this
                                                                                                                                                                                                                                    Returns
```

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void grad_relayIfNeeded(pkt_t xdata *pkt, pkt_t xdata *gradSeg) {
   // seg must refer to a packet segment of type SEG_TYPE_DISCOVERY
   // or SEG_TYPE_GRADIENT. Relay pkt if appropriate, else just
                                                                                                                                                                                                                                                                                                                                                                                      bit grad_isForMe(pkt_t xdata *gradSeg) {
   // seg must refer to a packet segment of type SEG_TYPE_DISCOVERY
   // or SEG_TYPE_GRADIENT. Returns true if the packet is destined
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      void grad_updateSeg(pkt_t xdata *pkt) {
   // find the SEG_TYPE_DISCOVERY or SEG_TYPE_GRADIENT segment in this
   // packet. In-place, fixup current sequence number and cost info.
   // Currently, this routine is used to update ARQ packets when they
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      bit grad_segIsFresh(pkt_t xdata *gradSeg) {
    // seg must refer to a packet segment of type SEG_TYPE_DISCOVERY
    // or SEG_TYPE_GRADIENT. Updates cost tables, returns true if
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   dest);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     pkt_t xdata *grad_makePkt(pkt_t xdata *pkt, node_id dest) {
   // Tack a GRAd routing header on the front of this packet. If the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // the cost isn't known, it creates a discovery packet.
pkt_t xdata *seg = pkt_alloc();
pkt_size(seg) = sizeof(gradPayload);
                                                                                                                                                                                                                                                                                                    gradPayload xdata *gp = pkt_payload(gradSeg);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     // this packet hasn't been seen before.
return ct_update((gradPayload xdata *)pkt_payload(gradSeg));
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             return seg;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      pkt_type(seg) = grad_prepPayload((gradPayload xdata *)pkt_payload(seg)
                                                                                                                                                                                                                                                             return (gp->fDestination == nodeID())
                                                                                                                                                                                                                                                                                                                                                   // for this node (dest is either BROADCAST_NODE or this node).
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    pkt_next(seg) = pkt;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // cost to dest is known, it creates a regular GRAd data packet. If
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       pkt_type(gradSeg) = grad_prepPayload(gp, gp->fDestination);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              gp = (gradPayload xdata *)pkt_payload(gradSeg);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               if ((gradSeg = grad_find_segment(pkt)) == NULL) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 gradPayload xdata *gp;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            pkt_t xdata *gradSeg;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // are retransmitted.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      if (cost == COST_UNKNOWN)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   } else {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  stats_origPkt();
return SEG_TYPE_GRADIENT;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    payload->fCostBudget = cost;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      return SEG_TYPE_DISCOVERY;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     stats_floodPkt();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            payload->fCostBudget = DEFAULT_DISCOVERY_COST;
                                                                                                                                                                                                                  (gp->fDestination == BROADCAST_NODE);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // note a routed packet
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     // note a flood packet
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                // link pkt in as next in line
```

File: id.h

```
#ifndef ID_H
#define ID_H
unsigned char nodeID();
                                            char *nodeName();
                                                                                                                                                                                                                                                         product without first obtaining appropriate licenses from MIT. MIT makes no representations about the suitability of this software for
                                                                                                                                                                                                                                                                                                                                                  or adapted as the basis of a commercial software or hardware
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      This MIT Media Laboratory project was sponsored by the Defense Advanced Research Projects Agency, Grant No. MOA972-99-1-0012.
                                                                                                                                                                                                                                                                                                                                                                                              be obtained from MIT.
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        Description: header file for node IDs
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             -*- Mode: C++ -*-
                                                                                                                                                                             warranty.
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```

File: id.c

#endif

```
// -*- Mode: C++ -*-
//
// File: id.c
// Description: defines nodeName() and nodeID()
//
// Copyright 2001 by the Massachusetts Institute of Technology. All
// rights reserved.
```

```
#define NODE_NAME "Zelkova"
                                                                                                                                                                                                                                                                                                                                                                                                                                              #ifndef NODE_NAME
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                #include "id.h'
                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // Maybe.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // NODE_NAME can be defined from the command line
                                  // #define
                                                 // #define
                                                                                                                                                                                                                                                                                                                                                                                                            // #define
                                                                                                                                                                                                                                                                                                                                                                                                                             // #define
                  #define
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               "Yew"
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                                                                                                                                                                                                                                                                                                                                                                            0x44
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              The
```

```
char *nodeName() {
  return NODE_NAME;
}

unsigned char nodeID() {
  return NODE_NAME[0];
}
```

File: mac.h

```
// Pass a packet to the MAC layer.
                                                 void mac_recvPkt(pkt_t xdata *pkt);
                                                                                                                                            // the GRAd thread.
                                                                                                                                                                                                                                                                         void mac_xmitPkt(pkt_t xdata *pkt);
                                                                                                                                                                                                                                                                                                                                                                                                                 // (This is a feature, not a bug.)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            void mac startTimer();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      // void mac_task(void) _task_ MAC_TASK;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      #include "pkt.h'
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               #define MAC_H
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         #ifndef MAC_H
                                                                                                                                                                                      // by anybody that wishes to send a packet, but normally called from
                                                                                                                                                                                                                               // queue a packet for subsequent transmission by the MAC task.
                                                                                                                                                                                                                                                                                                                                                                                                                                                               ^\prime/ transmitted or received, so counting stops when the radio is active.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      // Grab TMR1 and use it to count down gBackoffCounter for MAC timing.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             '/ TMR1 is "stolen" by the radio whenever a packet is actively being
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // File:
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         product without first obtaining appropriate licenses from MIT. MIT makes no representations about the suitability of this software for
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If GRAD runs in a separate thread
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           For any other uses of this
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```

```
// this will queue the packet until GRAd fetches it. Otherwise, it is
// passed directly to grad_recvPkt() for processing.
```

#endif

File: mac.c

```
#include "mac.h"
                                   #include
                                                                   #include
                                                                                                      #include
                                                                                                                                         #include
                                                                                                                                                                         #include
#include
                                                                                                                                                                                                             #include
                                                                                                                                                                                                                                                                                                                                                                                                                       queue for outgoing and incoming packets
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             warranty.
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           Advanced Research Projects Agency, Grant No. MOA972-99-1-0012.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               This MIT Media Laboratory project was sponsored by the Defense
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     Copyright 2001 by the Massachusetts Institute of Technology.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            Description: medium access.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      -*- Mode: C++ -*-
"screen.h"
                                                                                                      <stdlib.h>
                                                                                                                                      <rtx51tny.h>
                                                                                                                                                                         <aduc824.h>
                                                                                                                                                                                                             "vector.h"
                                                                                                                                                                                                                                             "stats.h"
                                                                                                                                                                                                                                                                                "arbor.h"
                                "appr.h"
                                                                "rad.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            mac.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                It is provided "as is" without express or implied
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        Permission to use, copy, or modify this
                            for appr_didXmit()
                                                                rad_xmitPkt()...
                                                                                                      for rand()
                                                                                                                                         for K SIG, etc
                                                                                                                                                                         for register defs
                                                                                                                                                                                                             for DEFINE_VECTOR()...
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            defer transmission until presumed safe.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        All
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              this
```

```
static unsigned char generateBackoff() {
  // compute a random delay, measured in tics, according to
  // current backoff exponent.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                static unsigned char const _mindly[MAX_BACKOFF] = { 0x02, 0x04, 0x08, 0x10, 0x20, 0x40, 0x80, 0x80
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                static unsigned char const _masks[MAX_BACKOFF] = {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   unsigned char gBackoffCounter;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             #define MAC_QUEUE_SIZE 10
DEFINE_VECTOR(gMacQueue, MAC_QUEUE_SIZE);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  #define MAC_BACKOFF_TICS (0x10000 - 5000)
                                    static void decrementBackoff() {
                                                                            #if 0
                                                                                                                                                                                                                       static void incrementBackoff() {
                                                                                                                                                                                                                                                                                                                                                                  static void resetBackoff() {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // gBackoffExponent is the exponent of the backoff. The range of possible
// backoff values returned by backof() looks something like this:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            #define MAX_BACKOFF 8
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             static unsigned char gBackoffExponent;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // binary exponential backoff
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // radio is in use
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // g=1:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // g=0:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // the next packet.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // counts down whenever radio is idle.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // g=3: ..
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      // g=2:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                // \, {	t dly:} \,\, 0123456789012345678901234567890123456789012345678
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // queue for packets waiting to be transmitted by MAC_TASK
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                // 5 mSec, or once every 5000 TMR1 tics, not counting when the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // non-essential timing: we want to generate a TRM1 ISR once every
if (gBackoffExponent != 0) gBackoffExponent--;
                                                                                                                                                                                   if (gBackoffExponent != MAX_BACKOFF-1) gBackoffExponent++;
                                                                                                                                                                                                                                                                                                                          gBackoffExponent = 0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              \label{eq:dly} $$dly = _mindly[gBackoffExponent] + (rand() & _masks[gBackoffExponent]); $$ stats_backoff(dly); $$ // log longest backoff $$
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               0x07, 0x0f, 0x1f, 0x3f, 0x7f, 0x7f, 0x7f, 0x80
                                                                                                                                                                                                                                                                                                                                                                                                                                                                            return dly;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          unsigned char dly;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         When it hits zero,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               ₩
e
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               send
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void tmr1_interrupt(void) interrupt 3 using 2 {
    // Called regularly whenever TMR1 is configured as the MAC backoff
    // counter, namely, whenever the radio isn't sending or receiving.
    // This has the effect that gBackoffCounter only decrements
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   void mac_task(void) _task_ MAC_TASK {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // MAC routines
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            mac_startTimer();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            gBackoffCounter = 0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         vector_init(VECTOR(gMacQueue), MAC_QUEUE_SIZE);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 while (1) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                resetBackoff();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // one-time initialization
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            The actual transmission is handled in this thread
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         loop: [1] wait for a packet to appear in gMacQueue
[2] set backoff counter, wait for it to counter
[3] if packet is still in gMacQueue, transminum of the counter of t
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  MAC transmit thread.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      // Initialize the backoff counter according to the current backoff
// exponent and then wait until it counts down to zero
gBackoffCounter = generateBackoff();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         SCREEN_TASK(("mac_task(1)"));
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    pkt_t xdata *pkt;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             if ((pkt = vector_dequeue(VECTOR(gMacQueue))) != NULL) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           while (gBackoffCounter > 0)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   while (vector_count(VECTOR(gMacQueue)) == 0)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // queue in the interim.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // backoff has expired. If there's still a packet available
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          / format and transmit the packet. Tell APP that the packet
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  / since some other thread might wish to prune the packet from the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        / queue it until after we've waited for the backoff interval,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      / Wait for a packet to become available. Don't remove from the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           appr_didXmit(pkt);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  SCREEN_TASK(("mac xmt: ")); PKT_PRINT(pkt);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // tmr1_interrupt() will signal us when gBackoffCounter hits os_wait2(K_SIG, 0);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        os_wait2(K_SIG, 0);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              pkt_free(pkt);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       rad_xmitPkt(pkt);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     resetBackoff();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           was sent, then free it.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   [2] set backoff counter, wait for it to count down[3] if packet is still in gMacQueue, transmit it[4] loop
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // mac_xmitPkt() will generate signal
```

```
void mac_xmitPkt(pkt_t xdata *pkt) {
                                                                                                                                                                                                                                                                                                                  // throw away the oldest.
                                                                                                                                                                                                                                                                                                                                                  // Called by anybody that wishes to send a packet, but normally // called from the application thread. If the queue fills up,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        void mac_startTimer() {
    // Configure TMR1 to count down MAC backoff tics, generating an
                                                                                                                                                                                                                                                                                                                                                                                                                         // queue a packet for subsequent transmission by the MAC task
                            pkt_free(vector_shove(VECTOR(gMacQueue), pkt));
// stats_macQueuePkt(vector_count(VECTOR(gMacQueue)));
if (rad_isBusy()) incrementBackoff();
os_send_signal(MAC_TASK);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           TMOD |= BITMASK(0,0,0,1,0,0,0,0); // 16 bit mode for TMR1
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     TR1 = 0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    if (gBackoffCounter > 0) {
                                                                                                                                                                            // ## don't call until MAC_TASK has been started
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        ET1 = 1;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     TR1 = 1;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           TH1 = MAC_BACKOFF_TICS>>8;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               TMOD &= 0x0f;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        TL1 = MAC_BACKOFF_TICS&0xff; // ...
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           TH1 = MAC_BACKOFF_TICS>>8;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // when the airwaves are idle. When gBackc
// this ISR sends a signal to the MAC task.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        TL1 = MAC_BACKOFF_TICS&0xff; // ...
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // see also rad_startTimer() in rad.c
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    if (--gBackoffCounter == 0) isr_send_signal(MAC_TASK);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        interrupt once every 1 mSec.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     // enable TMR1 interrupts
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // stop running
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // clear bits for TMR1
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // start running
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // setup reload value
// tell mac that a packet is waiting
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // reload TMR1
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 When gBackoffCounter hits zero,
```

File: pkt.h

```
// A packet carries information among nodes. A packet has an external
// and an internal representation. The external form of a packet is a
// serial stream of bytes, passed to the radio. The internal form is
                                            typedef enum
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            #define PKT_H
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             #ifndef PKT_H
                                                                                                                                                                                                                                                                                           #define MAX_PAYLOAD_SIZE 16
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // a linked list of pkt structures.
                                                                                                 // listed here.
                                                                                                                                                                                          // Each packet segment carries a type with it. Perhaps this is not
                                                                                                                                                                                                                                                                                                                                            // cost table reports.
                                                                                                                                                                                                                                                                                                                                                                                        // payload size determined by size of largest packet, currently the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // of the {	t pkt} list when generated or {	t popped} from the list when
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // an abstraction layer, and can be conveniently appxed onto the head
                                                                                                                                             ^\prime/ the cleanest abstraction, but all the specific packet types are
SEG_TYPE_EOP =
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              or adapted as the basis of a commercial software or hardware
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      to distribution in whole or in part, specific prior permission must be obtained from MIT. These programs shall not be used, rewritten,
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             This MIT Media Laboratory project was sponsored by the Defense Advanced Research Projects Agency, Grant No. MOA972-99-1-0012.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         -*- Mode: C++
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       makes no representations about the suitability of this software for any purpose. It is provided "as is" without express or implied
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    product without first obtaining appropriate licenses from MIT. MIT
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         separated from this distribution directory structure, this
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       purposes only and without fee is hereby granted, provided that this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        Media Laboratory, MIT. Permission to use, copy, or modify this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                This distribution is approved by Walter Bender, Director of the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  For general public use.
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            Copyright 2001 by the Massachusetts Institute of Technology.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         Description: support for packets, segments and payloads
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            software and its documentation for educational and research
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        endorsement should be inferred.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    position or the policy of the Government, and no official
0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   Each pkt structure corresponds to
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    All
```

```
#define pkt_payload(p) ((p)->fPayload)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // get/set the packet type for this segment
// seg_type pkt_getType(pkt_t xdata *pkt);
// void pkt_setType(pkt_t xdata *pkt, seg_type type);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       void pkt_free(pkt_t xdata *head);
void pkt_print(pkt_t xdata *seg);
                                                                                                           pkt_t xdata *pkt_find_segment(pkt_t xdata *pkt, seg_type type);
                                                                                                                                                                                                                                                                                                                                                      #define pkt_next(p) ((p)->fNext)
                                                                                                                                                                                                                                                                                                                                                                                                     // void pkt_setSize(pkt_t xdata *pkt, unsigned char size);
                                                                                                                                                                                                                                                                                                                                                                                                                                                             #define pkt_size(p) ((p)->fSize)
// get/set the number of bytes in the payload.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        #define pkt_type(p) ((p)->fType)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         pkt_t xdata *pkt_copy(pkt_t xdata *pkt);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        pkt_t xdata *pkt_alloc();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           void pkt_init();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 typedef struct _pkt_t {
    struct _pkt_t xdata *fNext;
                                                        // chain, returning NULL if not found
                                                                                                                                                            // unsigned char xdata *pkt_getPayload(pkt_t xdata *pkt);
                                                                                                                                                                                                                                                                      // void pkt_setNext(pkt_t xdata *pkt, pkt_t xdata *next);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                // make a "deep copy" of pkt
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // free a chain of packet segments
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // allocate a single packet segment
                                                                                                                                                                                            // reference the first byte of the payload
                                                                                                                                                                                                                                                                                              // pkt_t xdata *pkt_getNext(pkt_t xdata *pkt);
                                                                                                                                                                                                                                                                                                                            // get/set the next packet in the list of packets
                                                                                                                                                                                                                                                                                                                                                                                                                                     // unsigned char pkt_getSize(pkt_t xdata *pkt);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // initialize the packet system
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  unsigned char fPayload[MAX_PAYLOAD_SIZE];
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                unsigned char fSize;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        seg_type fType;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       SEG
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             SEG_TYPE_APPX,
SEG_TYPE_PING,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          SEG_TYPE_COST_L,
SEG_TYPE_COST_H,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            MAX_SEG_
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 SEG_TYPE_ACK,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            SEG_TYPE_ARQ,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       SEG_TYPE_ADC,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  SEG_TYPE_STATS,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              SEG_TYPE_TEXT,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         SEG_TYPE_DISCOVERY,
                                                                                find a packet segment of the given type in the packet
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 SEG_TYPE_GRADIENT,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       TYPE TIME
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               TYPE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 06
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                03
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           0a
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          04
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    payload
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  payload contains logging statistics
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             payload contains high half of cost table
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   payload contains gradient routing info
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 payload contains reply
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            payload contains request for reply
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        payload contains low half of cost table
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           payload contains discovery routing request
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      payload contains params for appx process
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  payload contains text
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           ping packet
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  report
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       contains analog readings
```

```
// print one segment in hex
void pkt_dumpHex(pkt_t xdata *pkt);
// print a string of segments in hex
#endif
```

File: pkt.c

```
#include "appx.h"
                                                                                                                                                              #include
                                                                                                                                                                                                                                                                             #include <string.h>
                                                                                                                                                                                                                                                                                                                    #include
                                                                                                                                                                                                                                                                                                                                                            #include "constell.h"
                                                                                                                                                                                                                                                                                                                                                                                                   #include "arbor.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                    #include "pkt.h"
// managing packets
                                                                                                                                                                                                 #include
                                                                                                                                                                                                                                     #include "screen.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   warranty.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           product without first obtaining appropriate licenses from MIT. MIT makes no representations about the suitability of this software for
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      software, in original or modified form, including but not limited to distribution in whole or in part, specific prior permission must be obtained from MIT. These programs shall not be used, rewritten, or adapted as the basis of a commercial software or hardware
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    copies and supporting documentation. If individual files are separated from this distribution directory structure, this
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   copyright notice and the original authors' names appear on all
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      Media Laboratory, MIT. Permission to use, copy, or modify this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          This distribution is approved by Walter Bender, Director of the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         For general public use.
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              rights reserved.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  Copyright 2001 by the Massachusetts Institute of Technology.
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                copyright notice must be included. For any other uses of this
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           Advanced Research Projects Agency, Grant No. MOA972-99-1-0012.
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                                                                                                                                                                                              "grad.h"
                                                                                                                                                                                                                                                                                                                    <stdio.h>
                                                                                                                                                   "arq.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         pkt.c
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          It is provided "as is" without express or implied
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         All
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```

```
static void _pkt_free_seg(pkt_t xdata *seg) {
   // return a single packet segment to the freelist
   // PRINTF(("pkt_fs(%x) ", (short)seg));
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   pkt_t xdata *pkt_alloc() {
   // pop a packet segment from the freelist
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             static pkt_t xdata _pkts[MAX_PACKETS];
                                                                                                   void pkt_free(pkt_t xdata *seg) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          void pkt_init() {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              static char _is_valid(pkt_t xdata *p) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         #define MAX_PACKETS 30
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           static unsigned char gAvail = 0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        static pkt_t xdata * data gFree = NULL;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // a global pool of pkt structures
                                                                                                                               // free the entire packet chain headed by head.
                                                                         while (seg) {
                                                                                                                                                                                                                                                                                                                                                                if (!_is_valid(gFree)) {
   printf("freelist clobbered");
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             if (gFree == NULL) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           pkt_t xdata *p;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               while (i--) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         gAvail = 0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 gFree = NULL;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   gFree = seg;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          seg->fNext = gFree;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    gAvail++;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          if (!_is_valid(seg)) return;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    return (_pkts <= p) && (p < &_pkts[MAX_PACKETS]);
                                                                                                                                                                                                         return p;
                                                                                                                                                                                                                                     p->fNext = (short)0;
                                                                                                                                                                                                                                                           SCREEN(("avail=%2bu", gAvail));
                                                                                                                                                                                                                                                                                       gAvail--;
                                                                                                                                                                                                                                                                                                                                                                                                                  gfree = p->fNext;
                                                                                                                                                                                                                                                                                                                                                                                                                                              p = gFree;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             int i=MAX_PACKETS;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         SCREEN(("Avail=%2bu", gAvail));
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // PRINTF(("pkt_a() => %x ", (short)gFree));
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                // set up the pool of packet structures
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 _pkt_free_seg(&_pkts[i]);
                                               pkt_t xdata *next = pkt_next(seg);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                printf("no more packets");
while (1);
                                                                                                                                                                                                                                                                                                                                         while (1);
seg = next;
                       _pkt_free_seg(seg);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // debug
```

```
pkt_t xdata *pkt_find_segment(pkt_t xdata *pkt, seg_type type) {
   // find a packet segment of the given type in the packet
   // chain, returning NULL if not found
                                                                                                                      static unsigned char code toHex[16] = {
   '0','1','2','3','4','5','6','7',
   '8','9','a','b','c','d','e','f'};
                                                                                                                                                                                                                                                                                                                                                                                                                                                         static unsigned char pkt_countsegs(pkt_t xdata *pkt) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    #define PKT_SIZE_FLAG 0xC0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      pkt_t xdata *pkt_copy(pkt_t xdata *pkt) {
   pkt_t xdata *first = NULL;
                            static void puthex(unsigned char ch) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               #define SEG_COUNT_FLAG 0x80
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // since we're sending raw binary over the serial port, the
// author of the server wanted a little error check to help
// stay in sync. Each segment count byte has the high order
// bit turned on, each packet size byte has the high two order
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // make a deep copy of a packet chain
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // bits turned on.
                                                                                                                                                                                                                                                                                                                                                                                                    while (pkt != NULL) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       pkt_t xdata *prev = NULL;
putchar(toHex[ch>>4]);
                                                                                                                                                                                                                                                                                                                                                                                                                                      unsigned char i = 0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              return NULL;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    while (pkt != NULL) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        return first;
                                                                                                                                                                                                                                                                                return i;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            while (pkt != NULL) {
                                                                                                                                                                                                                                                                                                                                         pkt = pkt_next(pkt);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      pkt = pkt_next(pkt);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  if (pkt_type(pkt) == type) return pkt;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          pkt_t xdata *seg = pkt_alloc();
// I could be clever and only copy the part of the payload that's
// active, but ....
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                pkt = pkt_next(pkt);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  memcpy(seg, pkt, sizeof(pkt_t));
if (prev == NULL) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  prev = seg;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            else {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          pkt_next(prev) = seg;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        first = seg;
```

```
putchar(toHex[ch&0x0f]);
}

void pkt_print(pkt_t xdata *seg) {
  unsigned char i = seg->fSize;
  char *p = pkt_payload(seg);
  puthex(i+1);
  puthex(seg->fType);
  while (i-) {
    puthex(*p++);
  }
}

void pkt_dumpHex(pkt_t xdata *pkt) {
    // dump pkt to serial port in sligtly formatted hex form
    printf("\n");
    puthex(pkt_countsegs(pkt));
  while (pkt i= NULL) {
    printf("\n");
    puthex(pkt_next(pkt);
    pkt = pkt_next(pkt);
}
```

File: rad.h

```
#if O
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              #include "pkt.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      #ifndef RAD_H
#define RAD_H
pkt_t xdata *rad_recvPkt();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      void rad_xmitPkt(pkt_t xdata *pkt);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        void rad_init();
                                                                                                                                                                                                                                                                      // NOT to be called from the RADR_TASK thread.
                                                                                                                                                                                                                                                                                                                                                                                                   // Transmit contents of packet immediately. Kills RADR_TASK thread,
// handles transmission in caller's thread, the restarts RADR_TASK.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // receiving.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               bit rad_isBusy();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  void rad_printBuffer();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // cold start for the radio
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      // returns true whenever the radio is actively transmitting or
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  or adapted as the basis of a commercial software or hardware
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 warranty.
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               to distribution in whole or in part, specific prior permission must be obtained from MIT. These programs shall not be used, rewritten, % \left( 1\right) =\left( 1\right) +\left( 
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 This MIT Media Laboratory project was sponsored by the Defense Advanced Research Projects Agency, Grant No. MOA972-99-1-0012.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                Description: low-level radio support
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           copyright notice must be included.
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       copyright notice and the original authors' names appear on all
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        purposes only and without fee is hereby granted, provided that this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          software and its documentation for educational and research
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          For general public use.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          endorsement should be inferred.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          position or the policy of the Government, and no official
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    content of the information does not necessarily reflect the
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```

```
// Block until a buffer of data has been received. Parse the buffer
// into a pkt_t structure and (if CRC is valid) return it. If CRC is
// invalid, returns NULL. MUST be called from within RADR_TASK
void rad standby();
// shut down radio
```

File: rad.c

```
#include
                                                                       #include
                                                                                                    #include
                                                                                                                                     #include
                                                                                                                                                                     #include
                                                                                                                                                                                                   #include
                                                                                                                                                                                                                                                                                                                                                                                                 // warranty
                                #include
                                                                                                                                                                                                                                    #include "arbor.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     // -*- Mode: C++ -*-
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                                                                                                                                                                                                                                                                                                                                                                                                                              any purpose.
                                                                                                                                                                                                                                                                                                                                                                                                                                                               makes no representations about the suitability of this software for
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                or adapted as the basis of a commercial software or hardware
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    Media Laboratory, MIT.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         product without first obtaining appropriate licenses from MIT.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       copies and supporting documentation. If individual files are separated from this distribution directory structure, this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     copyright notice and the original authors' names appear on all
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      purposes only and without fee is hereby granted, provided that this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         software and its documentation for educational and research
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   Advanced Research Projects Agency, Grant No. MOA972-99-1-0012.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   Description: low-level I/O support for BART and TR1000 radio
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           be obtained from MIT. These programs shall not be used, rewritten,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           to distribution in whole or in part, specific prior permission must
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       This distribution is approved by Walter Bender, Director of the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         For general public use
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          endorsement should be inferred.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       position or the policy of the Government, and no official
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   This MIT Media Laboratory project was sponsored by the Defense
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  Copyright 2001 by the Massachusetts Institute of Technology.
                                                                                                                                                                                                                                                                                               g "rad.h"
g "pkt.h"
"appr.h"
                                "sync.h"
                                                                                                                                     "constell.h"
                                                                                                                                                                     <aduc824.h>
                                                                                                                                                                                                   <rtx51tny.h>
                                                                    "stats.h"
                                                                                                    "id.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               in original or modified form, including but not limited
                                                                                                                                                                                                                                                                                                                                                                                                                              It is provided "as is" without express or implied
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    Permission to use, copy, or modify this
                                                                                                                                                                                                for os_wait()..
                                                                                                                                                               for register defs
for appr_recvPkt() ...
                                                                                                                                     LEDs
                                                                                                    // for nodeID()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           All
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           The
```

```
void rad_export(pkt_t xdata *pkt);
// copy and convert the contents of a linked packet structure
// into "raw" format in the radio's internal buffer.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      static unsigned char _rad_getByte();
// get a single byte from the radio (via the BART chip)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    #define RESTART_HOLDOFF()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         #define AWAIT_BART() os_wait2(K_TMO | K_SIG,
// #define AWAIT_BART() os_wait2(K_SIG, 0)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               #include <stdio.h>
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      #include "screen.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          #include "mac.h"
                                       static void _rad_finishBARTXmit();
                                                                                                                                                               static void _rad_setBARTXmit();
                                                                                                                                                                                                                                       // write a single byte to the radio (via the BART chip
                                                                                                                                                                                                                                                                               static void _rad_putByte(unsigned char b);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // for receive mode.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     #define AWAIT_HOLDOFF()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        #define BART_IS_READY() (!BART_READY)
// finish any transmit in progress, then configure bart chip for receive.
                                                                                                                   // configure the bart chip for transmit mode
                                                                                                                                                                                                                                                                                                                                                           // module's internal buffer, reconfigure radio to receive
                                                                                                                                                                                                                                                                                                                                                                                                                                          static void _rad_xmitBuffer();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // into a linked packet structure.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              static pkt_t xdata *rad_import();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // into this module's internal buffer
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          static void _rad_recvBuffer();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              static void _rad_setRecvMode();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // Local function prototypes
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // Busy wait until holdoff flag is set. Assumes RESTART_HOLDOFF()
// has been invoked previously
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // TMR1 must roll over once every 35 tics.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               #define BART_HOLDOFF_TICS
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // convert the "raw" contents of the radio's internal buffer
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // configure radio to receive,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // the holdoff period.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // Set the holdoff timer counting.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // transition.
                                                                                                                                                                                                                                                                                                                                                                                                   // configure the radio to transmit, send a packet of data from this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             ^{\prime\prime} configure the radio (and bart chip, and timers, and data lines)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // essential timing: BART needs BART_CLK stable for 35 uSec after each
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        TF1 = 0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        TL1 = BART_HOLDOFF_TICS;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                Assuming a 12MHz system clock and a 1 uSec cycle time,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // for mac_startTimer()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     await a packet of data, and read
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            while (!TF1)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              Return NULL for bad packet.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               TF1 will be set at the end of
```

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// appears to have a bad checksum. Without resorting to a 'scope, // my guess is that data transfers between pdata and the radio are // slow, resulting in under- and over-runs.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      #define _crc_state() gCRC
static void _crc_init();
static unsigned char _crc(unsigned char c);
unsigned char hexToNibble(unsigned char ch);
                                                                                                                                                                                                                                   // When start_macTimer() is called, it sets up TMR1 to
                                                                                                                                                                                                                                                                                                                                                                                                   static vtime_t gRecvTime;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            #define STAGING_AREA pdata
#define STAGING_BUFFER_SIZE 0xfe
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 #ifdef STAGING_IN_PDATA #define STAGING_AREA pda
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // of byte in data space dedicated to a "staging" buffer for the
// low-level radio I/O. There are only 128 bytes of data space availabl
// in the system, so if choosing STAGING_BUFFER_SIZE is a tradeoff: too
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // STAGING_BUFFER_SIZE is hand chosen to fill out the area without
// overflowing it. It determines the maximum number of bytes that
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // segment this buffer resides
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // The radio requires high-speed data transfer into and out of a // dedicated buffer. The STAGING_AREA macro defines in which
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  static crc_t gCRC;
                                                                                                                                                                   // service decrements gMACBackoffCounter, and if it hits
                                                                                                                                                                                                                                                                                                          // TMR1 management
                                                                                                                                                                                                                                                                                                                                                                                                                                        // packet. Used as part of the time synchronization process
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           static unsigned char STAGING_AREA sRadBuf[STAGING_BUFFER_SIZE + 1];
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // Dedicated buffer in data space for radio I/O. See note in // _rad_recvBuffer() regarding the +1 .
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // #define STAGING_BUFFER_SIZE 43
#define STAGING_BUFFER_SIZE 43
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    #define STAGING_AREA data
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                // #define STAGING_IN_PDATA
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               typedef short crc_t;
                                                                // When start_radio_timer() is called, it sets up TMR1 to
                                                                                                                                    // zero, signals the MAC task.
                                                                                                                                                                                                    // interrupt once every millisecond. The TMR1 interrupt
                                                                                                                                                                                                                                                                                                                                            // place to cache RTC clock values at the onset of receiving a
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      // small and packet size is limited. Too large, data space is eaten up
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // may be transmitted in a radio packet. This controls the number
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              STAGING_IN_PDATA doesn't work. Every packet sent and received
set its flag every 35 uSec, and disables its interrupt flag to inhibit the calling of the interrupt service.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          There are only 128 bytes of data space available
                                                                                                                                                                                                                                                                                                                                            #if O
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   void int0_interrupt(void) interrupt 0 using 2 {
    // Notify the RADR_TASK that BART_READY has come true. Note that
    // INTO interrupts arrive as interrupt 0. This routine uses
    // register bank 2 to avoid copying registers.
    isr_send_signal(RADR_TASK);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   static void rad_startTimer() {
   // Configure TMR1 to auto-reload once every BART_HOLDOFF_TICS,
   // disable interrupts.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          //
This has the properties we want: when the radio is
// busy sending or receiving data, we want to inhibit
                                                                   #endif
                                                                                                                                                                                                                                                                                                                                                                                                                                                                          bit rad_isBusy() {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // initialization and interrupt code
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       bit gRadIsBusy;
void rad_printBuffer() {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          void rad_init() {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // the counting down of the gMACBackoffCounter.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  ET1 = 0;
TR1 = 0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     ITO = 1;
EXO = 1;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          _rad_setRecvMode();
                                                                                                                                                                                                                                for (i = 0; i<RAD_BUF_SIZE; i++) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       TR1000_CTI_DIRECTION = BITMASK(0,0,0,0,0,1,1,0); // setup mode ctl pins
TR1000_CTI_DRIVE = 0x00; // standard CMOS I/O
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              return gRadIsBusy;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      BART_DATA_DRIVE = 0x00;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        BART_DATA_CONTROL = 0 \times 00;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            RESTART_HOLDOFF();
                                                                                                                                                                                                                                                                        unsigned char i;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // enable external interrupts on INTO, edge trigger
ITO = 1;
// INTO edge triggered
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           MAC layer.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          is an approximate implementation of the 802.11 style
                                                                                                                                                                   printf("%02bx ", sRadBuf[i]);
if ((i+1)%16 == 0) puts("");
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // stop running
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    / disable TMR1 interrupts
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      // for pins PB0 - PB7
// standard CMOS I/O
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // enable INTO interrupts
// configure for receive mode
```

```
void radr_task() _task_ RADR_TASK {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       ::
                                                                                                                                                                                                                                            static void _rad_setRecvMode() {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    pkt_t xdata *rad_recvPkt() {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // packet is found, call mac_recvPkt() to process it.
gRadIsBusy = 0;
                           mac_startTimer();
                                                                                                                                                             gRadIsBusy = 1;
                                                   TR1000\_CTL1 = 1;
                                                                            TR1000_CTL0 = 1;
                                                                                                                             _rad_setBARTXmit();
                                                                                                                                                                                        rad_startTimer();
                                                                                                                                                                                                                                                                                                                                                                                                                                   // as captured by _rad_recvBuffer();
if ((pingSeg = pkt_find_segment(pkt, SEG_TYPE_PING)) != NULL) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 pkt_t xdata *pingSeg;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         pkt_t xdata *pkt;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              while(1) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            pkt_t xdata *p;
                                                                                                                                                                                                                                                                                                                           return pkt;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        pkt = rad_import();
                                                                                                                                                                                                                 // configure radio, BART, and TMR1 for receiving radio data
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // block (in _rad_recvBuffer()) until a low-level buffer of data
// has been received. Parse the buffer into a pkt_t structure
// and (if CRC is valid) return it. If CRC is invalid, returns
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               Receive Task
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // NULL.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    Repeatedly try to read a packet from the radio.
                                                                                                          _rad_finishBARTXmit();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       Receiving Data
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  rad_recvBuffer();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          p = rad_recvPkt();
if (p != NULL) {
                                                                                                                                                                                                                                                                                                                                                                               pp->fTimeR = gRecvTime;
                                                                                                                                                                                                                                                                                                                                                                                                       pingPayload xdata *pp = pkt_payload(pingSeg);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                SCREEN_TASK(("radr_task(1)"));
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    If there is a PING segment in the received packet, fill in the received time field with the onset time of reception, gRecvTime,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                appr_recvPkt(p);
else {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     stats_badRecvPkt();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      stats_goodRecvPkt();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 PKT_PRINT(p);
                                                                                                       // force BART into known mode
//
...
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // not a good packet
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      // note a good packet
                           // resume counting MAC backoff tics
                                                                                 // set TR1000 to receive mode
                                                                                                                                                                                        // momentarily steal TMR1
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      When a valid
```

```
static unsigned char _rad_getByte() {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            static void _rad_recvBuffer() {
                                                                                                                                                                                                                                              gRadIsBusy = 0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           p = sRadBuf;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  unsigned char data len;
unsigned char STAGING_AREA * data p;
unsigned char STAGING_AREA * data pEnd;
                            unsigned char b;
                                                                                                                                                                                                                                                                                  mac_startTimer();
                                                                                                                                                                                                                                                                                                               LED_OFF(ORANGE_LED);
AWAIT_HOLDOFF();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          gRadIsBusy = 1;
AWAIT_HOLDOFF();
                                                              // blocked. Assumes the radio is in receive mode
                                                                                       // receive a byte from the radio via the BART interface.
// BART receive buffer is empty, the caller's thread will
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         while (len != 0) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 len = _rad_getByte();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 LED_ON(ORANGE_LED);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               gRecvTime = sync_getLocalTime(); // capture time at onset of reception
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          rad_startTimer();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    while (!BART_IS_READY()) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                _rad_setRecvMode();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           pEnd = &sRadBuf[STAGING_BUFFER_SIZE];
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      LED_OFF (RED_LED);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             //\ [1] Force the BART chip to search for new sync header.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // fetch a packet of data from the radio into sRadBuf[].
                                                                                                                                                                                                                                                                                                                                                                                                         0 = 0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // [4] Return
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     AWAIT_BART();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          while ((len--) && (p<pEnd)) {
   *p++ = _rad_getByte();</pre>
                                                                                                                                                                                                                                                                                                                                                                                                                                                            if (p >= pEnd) break;
len = _rad_getByte();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              *p++ = len;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     // this loop can overshoot the buffer length by one, so // made the buffer one extra byte long...
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   [2] Read the byte. If it is not RAD_PKT_LEADER,
[3] Read in a series of segments. Each segment :
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         Read in a series of segments. Each segment starts with a byte count, followed by that many bytes of data. The subsequent byte is the byte count for the next segment. A byte count of zero terminates the chain.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  after a sync header.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 (in _rad_getByte()) will return the first character found
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // actively receiving
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // clear bad pkt indicator
// buzz until prior holdoff elapses
                                                                                                                                                                                                                                                                             // start counting MAC backoff again
                                                                                                                                                                                                                                                                                                                                           // no longer receiving
                                                                                                                                                                                                                                                                                                                                                                                                         // write terminating byte
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // got first char, stop counting mac tics
                                                                                             be
t
```

```
type) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    static pkt_t xdata *rad_import() {
   // read the radio's raw data buffer into pkt structures,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             static unsigned char _pkt_isReasonable(unsigned char len, unsigned char
                                                                                                                                                                                                                                                                                                                                                                                                                                                        pkt_t xdata * data pkt;
pkt_t xdata * data prev;
pkt_t xdata * data head;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // perform checksumming, etc. Return a packet structure
// if the data is intact, NULL otherwise
unsigned char STAGING_AREA *src;
unsigned char len, type;
unsigned short crcFound;
unsigned char xdata * data pay;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         return 1;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            if ((len == 0) || (len > MAX_PAYLOAD_SIZE+1)) return 0;
if ((type == SEG_TYPE_EOP) || (type == 0x88)) return 0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      RESTART_HOLDOFF();  // hold BART_CLOCK low for
// next call to _rad_getByte() will complete the holdoff
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       b = BART_DATA_IN;
BART_CLOCK = 0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      RESTART_HOLDOFF();
AWAIT_HOLDOFF();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  while (!BART_IS_READY()) {
   AWAIT_BART();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             return b;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // BART_READY line is now guaranteed to valid. Check its value, // block this thread if BART's input FIFO is empty.
                                                                                                                                                                                                                                                                                                                                             head = prev = NULL;
                                                                                                                                                                                                                                                                                                                                                                                                         src = &sRadBuf[0];
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // AWAIT_HOLDOFF();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 BART_CLOCK = 1;
                                                                                                                                                                                                                                                                                           while (1) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // try to filter out stupid packets before we allocate storage for them
                                                                                                                                                                                                                                                                                                                                                                               crc init();
                                                                                                                                                                                                                          len = _crc(*src++);
type = _crc(*src++);
                                                                                                               pkt_size(pkt) = len;
                               while (len--) {
                                                         pay = pkt_payload(pkt);
                                                                                   pkt_type(pkt) = type;
                                                                                                                                               pkt = pkt_alloc();
                                                                                                                                                                         len--;
                                                                                                                                                                                                   if (!_pkt_isReasonable(len,type)) break;
*pay++ = _crc(*src++);
                                                                                                                                                                      // account for type field just read.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // data now valid. latch it
// finish data transfer
// hold BART_CLOCK low for holdoff period
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // request the data
// hold BART_CLOCK high for holdoff period
// ...
```

```
void rad_xmitPkt(pkt_t xdata *pkt) {
    // Transmit a packet immediately. NOT to be called from within the
    // RADR_TASK thread.
    pkt_t xdata *pingSeg = pkt_find_segment(pkt, SEG_TYPE_PING);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // Transmitting Data
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      // If the packet contains a SEG_TYPE_PING segment, copy the
// nodeID and local time into it just prior to transmission.
if (pingSeg != NULL) {
                      // pkt_free(pkt); //
SCREEN_TASK(("rad_xmitPkt(3)"));
                                                                                                                                                          SCREEN_TASK(("rad_xmitPkt(2)"));
                                                                                                                                                                                                                                                                                                                                                                                                                                      os_delete_task(RADR_TASK); // stop the receiver
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        SCREEN_TASK(("rad_xmitPkt(1)"));
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              } else {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     if (_crc_state() == crcFound) {
   LED_OFF(RED_LED);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      if ((type == SEG_TYPE_EOP) && (len == 5)) {
   // good prospects. Read in last 4 bytes as hex chars,
   // compare against accumulated CRC value
   for (len = 0; len < 4; len+) {
     crcFound <<= 4;
     crcFound <<= 4;</pre>
os_create_task(RADR_TASK);
                                                                               // MAC is responsible for freeing the packet
                                                                                                                                   rad_export(pkt);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     crcFound = 0;
                                                                                                          _rad_xmitBuffer();
                                                                                                                                                                                                                                         pp->fTimeX = sync_getLocalTime();
                                                                                                                                                                                                                                                                       pp->fNodeID = nodeID();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          pkt_free(head);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            return head;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       prev = pkt;
                                                                                                                                                                                                                                                                                                pingPayload xdata *pp = pkt_payload(pingSeg);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 return NULL;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   LED_ON (RED_LED);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // link this packet into chain of packets
if (prev == NULL) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         } else {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           pkt_next(prev) = pkt;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  head = pkt;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // bad pkt indicator
// restart receiver
                                                                                                        // blurt
                                                    // free the packet
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // release bogus segments
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // a valid packet!
                                                                                                                                   // copy in to data-space buffer
```

```
static void _rad_xmitBuffer() {
    // send the contents of sRadBuf[] to the radio. sRadBuf[] is
    // expected to consist of one or more packets. Each packet starts
    // with a byte count, followed by that many bytes of data. The next
    // byte following is the number of bytes in the subsequent packet.
    // A byte count of zero terminates the chain. The terminating zero
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             void rad_export(pkt_t xdata *pkt) {
   // write the contents of the pkt structures headed by pkt into the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          dst = &sRadBuf[0];
                                                                                                                          LED_ON(AMBER_LED);  // indicate transmit mode
while ((len = *p++) != 0) {
                                                                                                                                                                                                                                                                                        TR1000\_CTL0 = 0;
                                                                                                                                                                                                                                                                                                                                                     gRadIsBusy = 1;
                                                                                                                                                                                                                                                                                                                                                                                     rad_startTimer();
                                                                                                                                                                                                                                                                                                                                                                                                                                                     unsigned char STAGING_AREA *p = sRadBuf;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     unsigned char len;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               sprintf(dst, "%04x\0", _crc_state());
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     *dst++ = _crc(5);
*dst++ = _crc(SEG
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     while (pkt) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           dst = &sRadBuf[0];
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     unsigned char xdata *pay;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  unsigned char len;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  unsigned char STAGING_AREA *dst;
                                                                                                                                                                                          LED_OFF(RED_LED);
                                                                                                                                                                                                                                                       TR1000\_CTL1 = 1;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // radio's low-level buffer, complete with checksum
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // is transmitted.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // rad_xmitBuffer();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // Now rad_buffer() has been loaded up. Send it...
_rad_putByte(0);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               ^{\prime}/ as a hex string, and a final terminating null
                                                                                                                                                                                                                                                                                                                        _rad_setBARTXmit();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // output a final segment with len = 5, type = EOP, payload = CRC
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        crc_init();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       *dst++ = _crc(len + 1);

*dst++ = _crc(pkt_type(pkt));

pay = pkt_payload(pkt);
                                                          while (len--) _rad_putByte(*p++);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             pkt = pkt_next(pkt);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  len = pkt_size(pkt);
                                                                                                rad_putByte(len);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             while (len--) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          *dst++ = _crc(*pay++);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         _crc(SEG_TYPE_EOP);
                                                                                                                                                                                       // clear bad pkt indicator
                                                                                                                                                                                                                                                          // configure TR1000 for ASK transmit
// ...
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // payload + type
// transmit terminating byte
                                                                                                                                                                                                                                                                                                                                                                                     // grab TMR1 for radio (no mac tics)
```

```
// In BART RECV MODE, bart reads serial data from the radio and
// writes it to the parallel port. BART_READY stays false until
// at least one byte is available in the fifo.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   static void _rad_putByte(unsigned char b) {
    // Send a byte to the radio via the BART interface chip. If
    // BART transmit buffer is full, the caller's thread will be
    // blocked. Assumes the radio is in transmit mode.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                 static void _rad_setBARTXmit() {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     // In BART_XMIT_MODE, bart reads bytes from the parallel port and // sends serial data to the radio. BART_READY stays true unless
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      // switching BART modes
AWAIT_HOLDOFF();

// ### SOME RADIOS SEEM TO GET HUNG HERE AT while (!BART_IS_READY()) { // wait until AWAIT_BART();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   mac_startTimer();
gRadIsBusy = 0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       BART_CLOCK = 0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    RESTART_HOLDOFF();
AWAIT_HOLDOFF();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        while (!BART_IS_READY()) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  AWAIT_HOLDOFF();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      BART_DATA_OUT = b;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              TR1000\_CTL1 = 1;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 TR1000_CTL0 = 1;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 BART_MODE = BART_MODE_XMIT; // Tell BART to switch to xmit mode
                                                                                                                                                                                BART_CLOCK = 0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                // AWAIT_HOLDOFF();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             RESTART_HOLDOFF(); // hold BART_CLOCK low for // next call to _rad_putByte() will complete the holdoff
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 BART_CLOCK = 1;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // BART_READY line is now guaranteed to valid. Check its value,
// block this thread if BART's input FIFO is full.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       LED_OFF(AMBER_LED);
                                                                                                                                                                                                                    // doesn't set the radio control lines.
                                                                                                                                                                                                                                                    // mode, nothing particularly bad happens. Note that this routine
                                                                                                                                                                                                                                                                                       ^\prime/ If this routine is called while BART is already in transmit
                                                                                                                                                                                                                                                                                                                       // - bart parallel port set to receive
// - bart in transmit mode and ready to receive host data
                                                                                                                                                                                                                                                                                                                                                                                              // the BART chip into a well defined state.) Upon exit:
                                                                                                                                                                                                                                                                                                                                                                                                                              // Configure BART to transmit data. (More importantly, set
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     the host fills up the fifo.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                AWAIT_BART();
                                      // wait until BART is ready
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // set up the data on the i/o lines // buzz until prior holdoff elapses \,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // finish data transfer
// hold BART_CLOCK low for holdoff period
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // announce the data
// hold BART_CLOCK high for holdoff period
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // indicate end of transmit mode
// resume counting MAC backoff tics
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // switch TR1000 to receive mode
                                                                      STARTUP.
```

```
static unsigned char _crc(unsigned char c) {
  if (gCRC < 0) {</pre>
                                                                                                                                                                                                                                                                                                                                                                                                                                               static void _crc_init() {
  gCRC = 0xflfl;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                static void _rad_finishBARTXmit() {
// auxiliary routines
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // The CRC polynomial is feeble but simple to compute...
                                     // CRC generation and checking
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // is asserted when the fifo is EMPTY.
while (BART_IS_READY()) {
   os_wait2(K_TMO, 0);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       BART_DATA_DIRECTION = RECV; // set data direction from BART BART_MODE = BART_MODE_RECV; // tell bart to enter receive mode // Unconventional: BART will assert BART_IS_READY() until its fifo
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 if (BART_MODE == BART_MODE_RECV) {
   // quit now if BART is already configured in receive mode,
   // else the "while (!BART_IS_READY()) ..." below would hang.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // Tell BART to leave transmit mode and wait for any buffered data // it has in its fifo to transmit before returning. Assumes that // BART has been in transmit mode, that TMR1 is set up as a holdoff // timer.
                                                                                                                                       return c;
                                                                                                                                                                                                                                         gCRC = (gCRC << 1) + c + 1;
} else {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // BART's transmit fifo is now empty.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                AWAIT_HOLDOFF();
BART_CLOCK = 0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        BART_DATA_DIRECTION = XMIT; // set data direction towards BART
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              while (!BART_IS_READY()) {
   AWAIT_BART();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                // BART asserts the BART_READY line while the fifo is draining,
// so we must handle the rare case that the fifo is full upon
// entering _rad_finishBARTXmit() by letting the fifo get to a
// non-full state before continuing...
                                                                                                                                                                                                      gCRC = (gCRC << 1) + c;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        return;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    drains. This is because in the recv mode, the BART_IS_READY()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // wait for BART's fifo to drain
// K_SIG won't work here...
```

```
unsigned char hexToNibble(unsigned char ch) {
   if (ch <= '9') {
      return ch - '0';
   } else if (ch <= 'F') {
      return ch - 'A' + 10;
   } else if (ch <= 'f') {
      return ch - 'a' + 10;
   }
}</pre>
```

File: screen.h

```
#define SCREEN_CLEAR() screen_clear()
#define SCREEN_TASK(string) screen_task_prefix(); printf string;
                                                                               screen_cleareol();
                                                                                                                                                                                                                                                              void screen_task_prefix(void);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        #include <stdio.h>
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                #ifdef SCREEN_ENABLE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // de-comment the following line to enable the SCREEN_xxx macros
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            #define SCREEN_H
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    #ifndef SCREEN_H
#define SCREEN(string)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     // File:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              Displayed on a HyperTerm or equivalent communications program,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 product without first obtaining appropriate licenses from MIT. MIT makes no representations about the suitability of this software for any purpose. It is provided "as is" without express or implied
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             Media Laboratory, MIT.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             Description: diagnostic printout to VT100 compatible screen
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        or adapted as the basis of a commercial software or hardware
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   copyright notice must be included.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       copies and supporting documentation. If individual files are
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      purposes only and without fee is hereby granted, provided that this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          software and its documentation for educational and research
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         This distribution is approved by Walter Bender, Director of the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                position or the policy of the Government, and no official
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               This MIT Media Laboratory project was sponsored by the Defense Advanced Research Projects Agency, Grant No. MOA972-99-1-0012.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              Copyright 2001 by the Massachusetts Institute of Technology.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                -*- Mode: C++ -*
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   #define SCREEN_ENABLE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   this will display diagnostics: each thread state is printed on
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  warranty.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    be obtained from MIT.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        to distribution in whole or in part, specific prior permission must
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            software,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           separated from this distribution directory structure, this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  copyright notice and the original authors' names appear on all
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 For general public use
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        endorsement should be inferred.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           content of the information does not necessarily reflect the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      rights reserved
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               its own line
                                                                                                                                                                                                                                                                                                                                                                                             screen_cleareol(void);
                                                                                                                                                                                                                                                                                                         screen_goto(unsigned char row, unsigned char col);
                                                                                                                                                                                                                                                                                                                                                 screen_clear(void);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        in original or modified form, including but not limited
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                These programs shall not be used, rewritten,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             Permission to use, copy, or modify this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   For any other uses of this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  All
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   The
```

```
goreen_goto(1, 1);

printf string

#define PKT_PRINT(pkt) pkt_print(pkt)

#else // SCREEN_ENABLE

#define SCREEN_CLEAR()
#define SCREEN_TASK(string)
#define SCREEN(string)
#define PKT_PRINT(pkt)

#endif // SCREEN_ENABLE

#endif // ifdef SCREEN_H
```

File: screen.c

```
#ifdef SCREEN_ENABLE
                                                                                                  #include "screen.h"
                                                                                                                                                                                                     warranty.
                                                                                                                                                                                                                                             any purpose. It is provided "as is" without express or implied
                                                                                                                                                                                                                                                                                                   makes no representations about the suitability of this software for
                                                                                                                                                                                                                                                                                                                                                                                                      or adapted as the basis of a commercial software or hardware
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 -*- Mode: C++ -*-
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```
#include <rtx51tny.h>
#include <stdio.h>

static unsigned char gCount;

void screen_cleareol() {
    printf("%bc[0K", 0x1b);
}

void screen_goto(unsigned char r, unsigned char c) {
    printf("%bc[%bd;%bdH", 0x1b, r, c);
}

void screen_clear() {
    printf("%bc[2J", 0x1b);  // erase screen
    gCount = 0;
}

void screen_task prefix() {
    unsigned char id = os_running_task_id();
    screen_goto(id+4, 1);
    printf("%2bd:%3bu: ", id, gCount++);
}

#endif // ifdef SCREEN_ENABLE
```

File: serial.h

```
#ifndef SERIAL_H
#define SERIAL_H
#endif // ifndef SERIAL_H
                                                                                                                                                                                                                      // bit serial_hasInput();
// returns true if a line of text has been typed
                                                                                                                                                                                                                                                                                                                                                                                            bit serial_charIsAvailable();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    void serial_init(void);
                                                                                       // returns the serial input buffer
                                                                                                                              // char *serial_input();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              or adapted as the basis of a commercial software or hardware
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File: serial.c

```
// -*- Mode: C++ -*-
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145

```
void serial_init() {
                                                                                                                                                                    #define BAUD_2400
                                                                                                                                                                                                      #define BAUD_4800
                                                                                                                                                                                                                                           #define BAUD_9600
                                                                                                                                                                                                                                                                       #define BAUD_19200
                                                                                                                                                                                                                                                                                                             #define BAUD_38400
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              #include <aduc824.h>
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             #include "arbor.h"
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PCON |= BITMASK(1,0,0,0,0,0,0); // "double" baud rate SCON = BITMASK(0,1,0,1,0,0,0,0); // mode 1, rcv enable, 8 bit
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   to distribution in whole or in part, specific prior permission must be obtained from MIT. These programs shall not be used, rewritten,
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          baud rates are:
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```

```
// Use TMR2 for baud rate generation
T2CON = BITMASK(0,0,1,1,0,0,0,0); // Rx,Tx BRG, timer, auto-reload
RCAP2H = Oxff;
RCAP2L = 256-BAUD_38400; // set baud rate
TR2 = 1; // run the clock
TI = 1;
}
bit serial_charIsAvailable() {
// return true if a character is in the input buffer
return RI;
}
```

File: stats.h

```
// note a valid packet received by the radio
                            void stats_goodRecvPkt();
                                                                                                                        void stats_reset();
                                                                                                                                                                                      } statsPayLoad;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                     typedef struct
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  #include "pkt.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             #define STATS
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         #ifndef STATS_H
                                                                                            // reset the statistics counters
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                                                                                                                                                                                                                                                    int fACKs;
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                H
                                                                                                                                                                                                                                                                                   fARQs;
                                                                                                                                                                                                                                                                                                                  fFlood;
                                                                                                                                                                                                                                                                                                                                              fRelay;
                                                                                                                                                                                                                                                                                                                                                                          forig;
                                                                                                                                                                                                                                                                                                                                                                                                         fBadRecv;
                                                                                                                                                                                                                                                                                                                                                                                                                                      fGoodRecv;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                     _statsPayload {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      stats.h
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       It is provided "as is" without express or implied
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                                                                                                                                                                                                                                                                                                                                                                                                    // # of good packets received
// # of bad packets received
                                                                                                                                                                                                                     max backoff generated
                                                                                                                                                                                                                                                    # of acks received
                                                                                                                                                                                                                                                                                                             # of packets relayed
# of discovery packets
                                                                                                                                                                                                                                                                                                                                                                        # of packets originated
                                                                                                                                                                                                                                                                              # of acks requested
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             For any other uses of this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            All
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   The
```

```
#endif
                                                                                    pkt_t xdata *stats_report(pkt_t xdata *next);
                                                                                                                                                                                            void stats_backoff(unsigned char backoff);
                                                                                                                                                                                                                                                                                             void stats_ack();
                                                                                                                                                                                                                                                                                                                                                               // note the sending of an ARQ
                                                                                                                                                                                                                                                                                                                                                                                              void stats_arq();
                                                                                                                                                                                                                                                                                                                                                                                                                                                          // note the origination of a discovery packet by GRAD
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // note the relaying of a packet by GRAD
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 void stats_origPkt();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // note a packet with bad CRC received by the radio
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     void stats_badRecvPkt();
                                                                                                                                                          // note the highest backoff seen
                                                                                                                                                                                                                                                              // note the reception of an ACK
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  void stats_floodPkt();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                void stats_relayPkt();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // note the origination of a packet by GRAD
                                                            // create stat report packet
```

File: stats.c

```
software, in original or modified form, including but not limited
                                                                                                                                                copyright notice must be included.
                                                                                                                                                                                                 separated from this distribution directory structure, this
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               Description: gather and report statistics on packet level I/O
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         File:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    -*- Mode: C++ -*-
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                stats.c
These programs shall not be used, rewritten,
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        The
```

```
void stats_relayPkt() {
   // note the relaying of a packet by GRAD
   INCREMENT(sStats.fRelay);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        void stats_goodRecvPkt() {
   // note a valid packet received at the radio level
   INCREMENT(sStats.fGoodRecv);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         #include <string.h>
#include "pkt.h"
#include "stats.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // or adapted as the basis of a commercial software or hardware
// product without first obtaining appropriate licenses from MIT. MIT
// makes no representations about the suitability of this software for
// any purpose. It is provided "as is" without express or implied
void stats_ack() {
   // note the reception of an ACK
   INCREMENT(sStats.fARQs);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              void stats_origPkt() {
   // note the origination of a packet by GRAD
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    void stats badRecvPkt() {
   // note a packet at the radio level with bad CRC
   INCREMENT(sStats.fBadRecv);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 void stats_reset() {
  // reset the statistics counters
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  #define INCREMENT(i) i = _inc_clamp(i)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    static _inc_clamp(int v) {
   if (v == MAX_INT) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              #define MAX_INT ((1<<(sizeof(int)*8))-1)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   #include <stdio.h>
                                                                                                                                                                                                            void stats_arq() {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              static statsPayload sStats;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // warranty.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  memset(&sStats, 0, sizeof(statsPayload));
                                                                                                                                                          INCREMENT (sStats.fARQs);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                     INCREMENT (sStats.forig);
                                                                                                                                                                                      // note the sending of an ARQ
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               } else {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      return v+1;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              return v;
```

```
void stats_floodPkt() {
    // note the origination of a discovery packet by GRAD
    INCREMENT(sStats.fFlood);
}

void stats_backoff(unsigned char backoff) {
    // note increased backoff, track highest seen
    if (backoff > sStats.fMaxBackoff) sStats.fMaxBackoff = backoff;

pkt_t xdata *stats_report(pkt_t xdata *next) {
    pkt_t xdata *pkt = pkt_alloc();
    pkt_type(pkt) = sizeof(statsPayload);
    pkt_ext(pkt) = sizeof(statsPayload);
    pkt_ext(pkt) = sizeof(statsPayload);
    return pkt;
}
```

File: sync.h

```
// A packet flagged SEG_TYPE_PING carries synchronization info.
// The fTimeX field is filled in (at the MAC level) just before
// the packet is transmitted. The fTimeR field is filled in
// with the ping that the packet started arriving.
                                                                                                                                                                                                                                     typedef unsigned int vtime_t;
                                                                                                                                                                                                                                                                                                                                   #define VIRTUAL_NOON (30 * 128)
                                                                                                                                                                                                                                                                                                                                                                              #define VIRTUAL_DAY (60 * 128)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // a virtual day for the system is defined as one minute
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // support for the real time clock and synchronization among nodes.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           #include "pkt.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        #define SYNC H
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   #ifndef SYNC_H
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                // 7680.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // measured in 128ths of a second.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // This distribution is approved by Walter Bender, Director of the
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```

```
#endif
                                                                                pkt_t xdata *sync_report(pkt_t xdata *next);
// Return a SEG_TYPE_TIME segment containing timing info for this
                                                                                                                                                                                                                                                                                                                         void sync_serviceSeg(pkt_t xdata *pingSeg);
                                                                                                                                                                                                                                                                                                                                                                                    // return the current real time for this node
                                                                                                                                                                                                                                                                                                                                                                                                            vtime_t sync_getLocalTime();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // set the ping interval.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     } timePayload;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              typedef struct
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               typedef struct _pingPayload {
                                                                                                                                                                                                                                                                 // xmit ping and the recv ping and adjusts the clock accordingly.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    void sync_setPingInterval(unsigned char tenths);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // reset the sync statistics counters
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             void sync_reset();
                                                                                                                                                                                                        // void sync_task(void)
                                                                                                                                                                                                                                                                                           // called when a segment arrives.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // A packet flagged SEG_TYPE_TIME carries information
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // nodes.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // real time clock and timing of the node relative to other
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              pingPayload;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             vtime_t fLocalTime;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              vtime_t fTimeX;
vtime_t fTimeR;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                int fSyncSent;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           vtime_t fMaxErr;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       unsigned char fNodeID;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  int fSyncRcvd;
                                                                                                                                                                        void sync_task(void) _task_ SYNC_TASK;
Periodically transmits a ping packet to node within range.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                _timePayload {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // this node's time
// maximum error seen recently
// # of sync packets sent
// # of sync packets received
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // receiver's time
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      // sending node id
// sender's time
                                                                                                                                                                                                                                                                                           Computes the error between the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           on the
```

File: sync.c

```
// -*- Mode: C++ -*-
// File: sync.c
// File: sync.c
// Description: support for decentralized synchronization
// Copyright 2001 by the Massachusetts Institute of Technology. All
// Tights reserved.
// This MIT Media Laboratory project was sponsored by the Defense
// Advanced Research Projects Agency, Grant No. MOA972-99-1-0012. The
// content of the information does not necessarily reflect the
// position or the policy of the Government, and no official
// endorsement should be inferred.
```

```
Ruminations on timing:
                                                                                                   #include <string.h>
                                                                                                                                          #include <stdlib.h>
                                                                                                                                                                          #include <rtx51tny.h>
                                                                                                                                                                                                             #include <limits.h>
                                                                                                                                                                                                                                                 #include <aduc824.h>
                                                                                                                                                                                                                                                                                    #include "screen.h"
                                                                                                                                                                                                                                                                                                                                                           #include "sync.h"
                                                                                                                                                                                                                                                                                                                                                                                              #include
                                                                                                                                                                                                                                                                                                                                                                                                                                 #include
                                                                                                                                                                                                                                                                                                                                                                                                                                                              #include "arbor.h"
                                                                                                                                                                                                                                                                                                                       #include "pkt.h"
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  product without first obtaining appropriate licenses from MIT. MIT makes no representations about the suitability of this software for any purpose. It is provided "as is" without express or implied
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      software,
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                                                                                                                                                                                                                                                                                                                                                                                                                              "constell.h"
                                                                                                                                                                                                                                                                                                                                                                                           "mac.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             notice must be included. For any other uses of this in original or modified form, including but not limited
                                                                                                // for register do
// for UCHAR_MAX
// for os_wait().
// rand()
// memset()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              Permission to use, copy, or modify this
                                                                                                                                                                       for os_wait()...
                                                                                                                                                                                                                                                 tor register definitions
```

Time is measured by reading the internal real time clock and adding an offset to it to form "local time." Adjustments to the clock are made by modifying the offset, not by resetting the real time clock.

Local time has a resolution of 1/128 seconds (determined by the real time clock hardware), and rolls over once every 60 seconds, or 7680 tics (where 1 tic = 1/128 second). Thus a "VIRTUAL_DAY" is defined as 7860 tics.

When a ping packet is received from a neighbor, the remote time is compared against the local time. If the remote time is "greater than" the local time, then the local clock is advanced. Similarly, if the remote time is "less than" the local time, the local clock is retarded.

Since time rolls over once every VIRTUAL_DAY, the meaning of "greater than" and "less than" must be considered carefully. In particular, define:

```
err = MOD(remote-local, VIRTUAL_DAY).
```

If err is less than VIRTUAL_DAY/2, then the remote time is ahead of the local time by err units. If err is greater than VIRTUAL_DAY/2, then local time is ahead by (VIRTUAL_DAY-err) units. Note that if err exactly equals VIRTUAL_DAY/2, then it's undefined as to which is

ahead.

The algorithm here is designed to set local time to an equally weighted average between remote time and local time, so if err is less than VIRTUAL_DAY/2, local time is advanced by err/2. If err is greater than VIRTUAL_DAY/2, then local time will be retarded by (VIRTUAL_DAY-err)/2. Note that the division by two introduces a roundoff error in the integer arithmetic used here; the low-order "half bit" is simulated by a random dither.

```
vtime_t sync_getLocalTime() {
   // fetch the current time from the RTC (plus offset)
   unsigned char sec, hthsec;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // send ping once every four seconds (on average)
#define SYNC_PING_INTERVAL (OS_TICS_PER_SECOND *
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            #define MAX(a, b)
#define IS_ODD(a)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           *
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // place to log statistics of the sync mechanism
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    static vtime_t sVTOffset;
                                                  static void rtc_retard(vtime_t units) {
                                                                                                                                                                                       static void rtc_advance(vtime_t units) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // real time clock manipulation
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          void sync_reset() {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      static timePayload sTimeStats;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // The offset added to the real time clock to form the local time
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             sVTOffset %= VIRTUAL_DAY
                         sVTOffset -= units;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                          do {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              memset(&sTimeStats, 0, sizeof(timePayload));
                                                                                                                                        sVTOffset %= VIRTUAL_DAY
                                                                                                                                                                   sVTOffset +=
                                                                                                                                                                                                                                                                          return vt % VIRTUAL_DAY;
                                                                                                                                                                                                                                                                                                         vt += hthsec + sVTOffset;
                                                                                                                                                                                                                                                                                                                                                              vt = sec;
                                                                                                                                                                                                                                                                                                                                                                                         } while (sec != SEC);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          vtime_t vt;
                                                                                                                                                                                                                                                                                                                                                                                                                  hthsec = HTHSEC;
                                                                                                                                                                                                                                                                                                                                                                                                                                              sec = SEC;
                                                                                                                                                                   units;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            (((a)>(b))?(a):(b))
(((a)&1)!=0)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            (OS_TICS_PER_SECOND * 5)
```

```
void sync_serviceSeg(pkt_t xdata *seg) {
   // Call sync_serviceSeg() when a SEG_TYPE_PING packet is received
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // case A: x=15 \ r=05, e=10 => advance by e/2 // case B: x=55 \ r=05, e=50 => retard by (60-e)/2 // case C: x=05 \ r=15, e=10 => retard by e/2 // case D: x=05 \ r=55, e=50 => advance by (60-e)/2
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     // note another ping packet received
sTimeStats.fSyncRcvd++;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               bit advance;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     sTimeStats.fMaxErr -= (sTimeStats.fMaxErr >> 2); // slow decay...
sTimeStats.fMaxErr = MAX(sTimeStats.fMaxErr, err); // ... fast rise
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     // sTimeStats.fMaxErr is a "leaky peak detector" // Note that with this code, fMaxErr will "stick" at (2^2)-1, or 3. // I could use fixpoint arithmetic to make it better, but it's not
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    if (pp->fTimeX > pp->fTimeR) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // Careful handling of unsigned numbers, mod VIRTUAL_DAY
// Pretend VIRTUAL_DAY is 60 seconds (one minute):
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  vtime_t err;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  pingPayload xdata *pp = pkt_payload(seg);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 if (err != 0) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         if (err > VIRTUAL_DAY/2) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // mac layer with the time of arrival.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      //\ {
m from\ a\ neighbor.} The packet has already been time stamped at the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // crucial
                                      else
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          else if (pp->fTimeX < pp->fTimeR) {
                                                                                                                                                                                                                                                                                                                                                                                                                       if (IS_ODD(err)) err += rand() & 1; // dither before divide by 2
err = err/2; // divide by 2
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      advance = !advance;
                                                                                                                                                                                                                                                                                                                                                          if (advance) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            err = VIRTUAL_DAY - err;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          advance = 0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   err = pp->fTimeR - pp->fTimeX;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    advance = 1;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             err = pp->fTimeX
                                                                                                                                                                                                                else
SCREEN_TASK(("tx=%4u tr=%4u er=0, mx=%u"
                                                                                                   rtc_retard(err);
                                                                                                                                                                             SCREEN_TASK(("tx=%4u tr=%4u er=-%u, mx=%u",
                                                                                                                                                                                                                                                    rtc_advance(err);
                                                                                                                                                                                                                                                                                                                    SCREEN_TASK(("tx=%4u tr=%4u er=+%u, mx=%u",
                                                                                                                                      pp->fTimeX, pp->fTimeR, err, sTimeStats.fMaxErr));
                                                                                                                                                                                                                                                                             pp->fTimeX, pp->fTimeR, err, sTimeStats.fMaxErr));
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 - pp->fTimeR;
// assume case A
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // assume case C
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           (60-e)/2
```

```
static void _bide(unsigned int tics) {
   // wait for the given number of tics to elapse.
   // approx 9.6 mSec, or 106 tics per second.
   // SCREEN_TASK(("_bide(1) %x", tics));
   while (tics != 0) {
                                                                                                                        pkt\_t \ xdata \ *sync\_report(pkt\_t \ xdata \ *next) \ \{ // \ create \ a \ packet \ that \ reports \ the \ current \ time \ statistics \ for \ this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          void sync_task(void) _task_ SYNC_TASK {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // Send a periodic PING message to immediate neighbors // once every PING_SECONDS seconds.
pkt_t xdata *pkt = pkt_alloc();
timePayload xdata *tp = pkt_payload(pkt);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 sync_reset();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    while (1) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            sVTOffset = 0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // one-time initialization
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            Sync thread.
                                                                                                                                                                                                                                                                                                                     // sleep for SYNC_PING_INTERVAL +/- 50%
_bide((SYNC_PING_INTERVAL/2) + (rand() % SYNC_PING_INTERVAL));
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               SCREEN_TASK(("sync_task(1) %x", sync_getLocalTime()));

// BIG_NOTE: Since the packet may spend an unknown amount of time
// in the MAC queue, the pingPayload->fTimeX field is filled in by
// rad.c just prior to transmission. This reduces timing errors.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // initiate a ping packet to advertize this node's local time
pkt_t xdata *pkt = pkt_alloc();
pkt_type(pkt) = SEG_TYPE_PING;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             tics -= t;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              os_wait2(K_TMO, t);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      t = (tics > UCHAR_MAX)?UCHAR_MAX:tics;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              unsigned char t;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        pkt_size(pkt) = sizeof(pingPayload);
                                                                                                                                                                                                                                                                                                                                                                                                                                                     sTimeStats.fSyncSent++;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // note another ping transmitted
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     mac_xmitPkt(pkt);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      // Lesser note: If a node packet decides to relay a ping packet
// rather than originate it, it would be a problem if the packet
// went out with the orinator's nodeID. Consequently, the fNodeID
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // prevent this possibility.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      '/ field is filled in at the same time as the fTimeX field to
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         pp->fTimeX, pp->fTimeR, sTimeStats.fMaxErr));
                                                                                   Copy the payload from the local sTimeStats.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               Each tic is
```

```
pkt_type(pkt) = SEG_TYPE_TIME;
pkt_size(pkt) = sizeof(timePayload);
pkt_next(pkt) = next;
pkt_next(pkt) = next;
sTimeStats.fLocalTime = sync_getLocalTime();
memcpy(pkt_payload(pkt), &sTimeStats, sizeof(timePayload));
return pkt;
}
```

File: vector.h

```
#ifndef VECTOR_H
#define VECTOR_H
                                           #define DEFINE_VECTOR(name, capacity) \
                                                                                                                                                                                                                                                                                                                                                   typedef struct _vector_t {
                                                                                                                                                                                                                                                                                                                                                                                                                                       typedef void OBJECT_SPACE * obj_t;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               #define OBJECT_SPACE xdata
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // A vector is a sequence of pointer-sized elements, densely packed // starting at index 0. The objects referred to by the vector
                                                                                       // create static storage for a vector, masquerading as an array of char
                                                                                                                                                                           } vector_t;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // obj_t is a general pointer into OBJECT_SPACE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // according to taste.
                                                                                                                                                                                                                       obj_t fElements[1];
                                                                                                                                                                                                                                                                   unsigned char fCapacity;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       are always in OBJECT_SPACE, which you can redefine
                                                                                                                                                                                                                                                                                                               unsigned char fCount;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           product without first obtaining appropriate licenses from MIT. makes no representations about the suitability of this software \,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   or adapted as the basis of a commercial software or hardware
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               warranty.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   be obtained from MIT.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       to distribution in whole or in part, specific prior permission must
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   software, in original or modified form, including but not limited
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               copyright notice must be included.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           separated from this distribution directory structure, this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       copies and supporting documentation. If individual files are
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   copyright notice and the original authors' names appear on all
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       purposes only and without fee is hereby granted, provided that this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           software and its documentation for educational and research
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               Media Laboratory, MIT. Permission to use, copy, or modify this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       This distribution is approved by Walter Bender, Director of the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           For general public use.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           content of the information does not necessarily reflect the
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   Copyright 2001 by the Massachusetts Institute of Technology. All
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   Description: manage a fixed sized array of pointer-sized objects
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       -*- Mode: C++ -*-
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   any purpose.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           endorsement should be inferred.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   position or the policy of the Government, and no official
char name[sizeof(vector_t) + ((capacity - 1) * sizeof(obj_t))]
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   It is provided "as is" without express or implied
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               These programs shall not be used, rewritten,
                                                                                                                                                                                                               // number of elements in the array
// size of the array
// a dense array of objects
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               For any other uses of this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           The
```

```
vector t *vector set(vector_t *v, obj_t element, unsigned char index);
// set the indexth entry of the table to element. Returns v on
// success, null if index is out of range.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      obj_t vector_ref(vector_t *v, unsigned char index);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              unsigned char vector_index_of(vector_t *v, obj_t element);
// return the index of the element in the vector, or -1 if not found
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        vector_t *vector_insert(vector_t *v, obj_t elem, unsigned char index);
// insert element into the vector. return v if inserted, or null if
// the vector was full prior to the call or if index is out of range.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // void vector_init(vector_t *v, unsigned char capacity)
#define vector_init(v, capacity) \
// obj_t vector_pop(vector_t *v);
                                                                                                   #define vector_push(v, e) vector_insert((v), (e), (v)->fCount)
                                                                                                                                                                                                                                                      #define vector_elements(v) ((v)->fElements)
                                                                                                                                                                                                                                                                                                                                                                                                                  #define vector_capacity(v) ((v)->fCapacity)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              #define vector_count(v) ((v)->fCount)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // unsigned char vector_count(vector_t *v);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      \#define\ vector\_clear(v)\ ((v)->fCount)=0,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // return the indexth entry of the table, or null if index out of range
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // returns it to make room for the new element as needed.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  obj_t vector_shove(vector_t *v, obj_t element);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // of range.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              vector_t *vector_swap(vector_t *v, unsigned char i1, unsigned char i2);
// swap two elements in the vector. return null if i1 or i2 are out
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // remove and return the element at the given index, or return // null if index is out of range.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         obj_t vector_remove(vector_t *v, unsigned char index);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   void vector_print(vector_t *v);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           #define VECTOR(v) ((vector_t *)&v)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // turn a static char reference into a vector pointer.
                                                                                                                                                       // vector_t *vector_push(vector_t *v, obj_t element);
                                                                                                                                                                                                                                                                                                              // obj_t *vector_elements(vector_t *v);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // unsigned char vector_capacity(vector_t *v);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // vector_t *vector_clear(vector_t *v);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // Everything else are macro definitions..
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // array. Unlike vector_push(), removes the first element and
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // initialize a vector. Must call this before first use
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              Like vector_push(), inserts element at the high end of the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       (v) \rightarrow fCount = 0; (v) \rightarrow fCapacity = (capacity)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          3
```

```
// void fast_vector_set(vector_t *v, obj_t element, unsigned char index);
#define fast_vector_set(v, e, i) ((v)->fElements[(i)]) = e
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     \texttt{#define fast\_vector\_ref(v, i) ((v)->fElements[(i)])}
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         obj_t fast_vector_remove(vector_t *v, unsigned char index);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       void fast_vector_insert(vector_t *v, obj_t element, unsigned char index);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  #define vector_is_empty(v) ((v)->fCount ==
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           #define vector_dequeue(v) vector_remove((v), 0)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         #define vector_enqueue(v, e) vector_insert((v), (e), (v)->fCount)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       \#define\ vector\_pop(v)\ vector\_remove((v), ((v)->fCount)-1)
#endif
                                                                                                                                                                                     #define fast_vector_enqueue(v, e) fast_vector_insert((v), (e), (v)->fCount)
                                                                                                                                                                                                                                                                                  #define fast_vector_pop(v) vector_remove((v), ((v)->fCount)-1
                                                                                                                                                                                                                                                                                                                                                                          #define fast_vector_push(v, e) fast_vector_insert((v), (e), (v)->fCount)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       void fast_vector_swap(vector_t *v, unsigned char index1, unsigned
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // fast versions - call only when you know arguments to be safe!
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // vector_t vector_enqueue(vector_t *v, obj_t element);
                                                                                    #define fast_vector_dequeue(v) fast_vector_remove((v), 0)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     // obj_t fast_vector_ref(vector_t *v, unsigned char index);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // boolean vector_is_full(vector_t *v);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // boolean vector_is_empty(vector_t *v);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // obj_t vector_dequeue(vector_t *v);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     char
```

File: vector.c

```
// -*- Mode: C++ -*-
// File: vector.c
// File: vector.c
// Description: manage fixed size arrays of pointer sized objects
// Copyright 2001 by the Massachusetts Institute of Technology. All
// rights reserved.
// This MIT Media Laboratory project was sponsored by the Defense
// Advanced Research Projects Agency, Grant No. MOA972-99-1-0012. The
// content of the information does not necessarily reflect the
// position or the policy of the Government, and no official
```

```
vector_t *vector_insert(vector_t *v, obj_t elem, unsigned char index) {
   if ((index < 0) | | (index > v->fCount) | | (v->fCount >= v->fCapacity)) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               void vector_print(vector_t *v) {
  unsigned char i;
                                                                                                                                                                                                                                                                                                                                       void fast_vector_insert(vector_t *v, obj_t elem, unsigned char index) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       #ifdef UNCALLED_SEGMENT
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       #ifdef UNCALLED_SEGMENT
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   #define NULL (void *)0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              #include "vector.h"
#include <stdio.h>
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // warranty.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // Media Laboratory, MIT. Permission to use, copy, or modify this // software and its documentation for educational and research
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // For general public use
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // endorsement should be inferred.
//
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             #ifndef NULL
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // copyright notice and the original authors' names appear on all
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                // any purpose.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   printf("\r\nv<%p>, cap=%bd, count=%bd ", v, v->fCapacity, v->fCount);
for (i=0; i<v->fCount; i++) {
   printf("[%d]%p%s",i,(v->fElements)[i], (i==v->fCount-1)?"":", ");
while (e2 > e0) {
                                                                                        e2 = &(v->fElements[v->fCount++]);
                                                                                                                                   e0 = &(v->fElements[index]);
                                                                                                                                                                                                                                                                                                    obj_t *e0, *e1, *e2;
                                              e1 = e2 - 1;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       fast_vector_insert(v, elem, index);
                                                                                                                                                                         // elements up by one.
                                                                                                                                                                                                                // Open a slot for an element at index by rippling all higher
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   to distribution in whole or in part, specific prior permission must be obtained from MIT. These programs shall not be used, rewritten, or adapted as the basis of a commercial software or hardware
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          product without first obtaining appropriate licenses from MIT. MIT makes no representations about the suitability of this software for
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   copies and supporting documentation. If individual files are separated from this distribution directory structure, this copyright notice must be included. For any other uses of this software, in original or modified form, including but not limited
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   purposes only and without fee is hereby granted, provided that this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              This distribution is approved by Walter Bender, Director of the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    return NULL;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                It is provided "as is" without express or implied
```

```
vector_t *vector_swap(vector_t *v, unsigned char i1, unsigned char i2)
  obj_t tmp, *elems;
  if ((i1 < 0) || (i1 >= v->fCount) ||
    (i2 < 0) || (i2 >= v->fCount)) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           obj_t vector_shove(vector_t *v, obj_t element) {
   // Like vector_push(), but removes (and returns) the first element
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        obj_t fast_vector_remove(vector_t *v, unsigned char index) {
  obj_t *e1, *e2, elem;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    obj_t vector_remove(vector_t *v, unsigned char index) {
  if ((index < 0) || (index >= v->fCount)) {
                            #ifdef UNCALLED_SEGMENT
void fast_vector_swap(vector_t *v, unsigned char i1, unsigned char i2) {
                                                                                            #endif
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               #ifdef UNCALLED_SEGMENT
                                                                                                                                                            return v;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       return fast_vector_remove(v, index);
                                                                                                                                                                                            elems[i2] = tmp;
                                                                                                                                                                                                                            elems[i1] = elems[i2];
                                                                                                                                                                                                                                                         tmp = elems[i1];
                                                                                                                                                                                                                                                                                        elems = v->fElements;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           return shoved;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  if (vector_is_full(v)) {
   shoved = fast_vector_remove(v, 0);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  obj_t shoved = NULL;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              return elem;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     while (index++ < v->fCount) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       elem = *e1;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 e1 = &(v->fElements[index]);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // for LRU structures.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // if the vector was full, making room for the new element. Good
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          v->fCount--;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // close the slot at index by rippling elements down (towards [0])
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 e2 = e1+1;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      *e0 = elem;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        fast_vector_insert(v, element, v->fCount);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // by one.
                                                                                                                                                                                                                                                                                                                                                        return NULL;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       return NULL;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           *e1++ = *e2++;
```

```
obj_t vector_ref(vector_t *v, unsigned char index) {
  if ((index < 0) || (index >= v->fCount)) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       #ifdef UNCALLED_SEGMENT
                                                 void print_vector(vector_t *v) {
                                                                                                      #define false (1==0)
                                                                                                                                  #define true (1==1)
                                                                                                                                                                                    #include <stdio.h>
                                                                                                                                                                                                              #include "arbor.h"
                                                                                                                                                                                                                                                             #ifdef TEST_VECTOR
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  vector_t *vector_set(vector_t *v, obj_t elem, unsigned char index)
if ((index < 0) || (index >= v->fCount)) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     unsigned char vector_index_of(vector_t *v, obj_t elem) {
   // return the index_of the element in the vector, or -1 if not found
                                                                                                                                                                                                                                                                                                                                            #ifdef UNCALLED_SEGMENT
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             #endif
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            #ifdef UNCALLED_SEGMENT
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     #endif
                                                                                                                                                                                                                                                                                       // #define TEST_VECTOR
                                                                                                                                                                                                                                                                                                               // test suite for vector code
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             #endif
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        obj_t *elems = v->fElements;
unsigned char i = v->fCount;
printf("v<%p>, count=%d, ", v, v->fCount);
                       unsigned char i;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      while (--i > 0) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    elems[i2] = temp;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            elems[i1] = elems[i2];
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      temp = elems[i1];
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                elems = v->fElements;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    return v;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           return -1;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                obj_t *elems, temp;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 } else {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       fast_vector_set(v, elem, index);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             return NULL;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    return fast_vector_ref(v, index);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           return NULL;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               if (elems[i] == elem) return i;
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void test(obj_t got, obj_t expected, char *msg) {
  if (got != expected) {
    printf("%s: got %p, expected %p\n", msg, got, expected);
} else {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 \label{eq:total} $$TEST(vector_dequeue((vector_t *)\&v), NULL, "getting from new vector"); $$TEST(vector_enqueue(VECTOR(v), (obj_t)0x1), VECTOR(v), "vector_enqueue returns vector");
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          void init() _task_ MAIN_TASK {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              DEFINE_VECTOR(v, CAPACITY);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  #define CAPACITY 6
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           #define TEST(got, exp, s) test(((obj_t)(got)), ((obj_t)(exp)),
                                                                                                                                             vector_enqueue(VECTOR(v), (obj_t)0x33);
vector_enqueue(VECTOR(v), (obj_t)0x44);
vector_enqueue(VECTOR(v), (obj_t)0x55);
vector_enqueue(VECTOR(v), (obj_t)0x65);
vector_enqueue(VECTOR(v), (obj_t)0x66);
vector_enqueue(VECTOR(v), (obj_t)0x66);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     vector_enqueue(VECTOR(v), (obj_t)0x2);
vector_enqueue(VECTOR(v), (obj_t)0x3);
vector_enqueue(VECTOR(v), (obj_t)0x3);
vector_enqueue(VECTOR(v)), (obj_t)0x4);
TEST(vector_count(VECTOR(v)), 4, "vector size mismatch");
TEST(vector_dequeue(VECTOR(v)), 0x1, "getting from vector");
TEST(vector_dequeue(VECTOR(v)), 0x2, "getting from vector");
TEST(vector_dequeue(VECTOR(v)), 0x3, "getting from vector");
TEST(vector_dequeue(VECTOR(v)), 0x4, "getting from vector");
TEST(vector_dequeue(VECTOR(v)), 0x4, "getting from vector");
                                  TEST(vector_is_empty(VECTOR(v)), false, "vector is not empty");
TEST(vector_is_full(VECTOR(v)), true, "vector is full");
                                                                                                                          vector\_enqueue(VECTOR(v),
                                                                                                                                                                                                                                                                                                                                                                                                                      TEST(vector_is_empty(VECTOR(v)), true, "vector is empty");
// TEST(vector_is_full(VECTOR(v)), false, "vector is not full");
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          puts("\r\n\r\nvector test\r\n");
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            for (i=0; i<v->fCount; i++) {
   printf("[%d]%p%s",i,(v->fElements)[i],
TEST(vector_enqueue(VECTOR(v), (obj_t)0x88), NULL, "putting to full
                                                                                                                                                                                                                                                                                                                              vector_enqueue(VECTOR(v), (obj_t)0x22);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         vector_init(VECTOR(v), CAPACITY);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    os_wait2(K_TMO, 4);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    serial_init();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           //ALL_LEDS_ON();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         LED_ON(AMBER_LED);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   LED INIT();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         PLLCON = 0 \times 00; // 12 MHz
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            printf("%s: okay\n", msg);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              (i==v->fCount-1)?"\n":", ");
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // set up baud rate
                                                                                                                      (obj_t)0x77);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   03
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1");
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       end");
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   1");
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  end");
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         vector");
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                (obj_t) "bogus")),
TEST(vector_ref(VECTOR(v), 4), NULL, "ref beyond end");
TEST(vector_ref(VECTOR(v), -1), NULL, "ref before beginning");
TEST(vector_ref(VECTOR(v), 2), 0x222, "ref 2");
TEST(vector_set(VECTOR(v), (obj_t)0x333, 4), NULL, "set beyond end");
TEST(vector_set(VECTOR(v), (obj_t)0x333, 2), VECTOR(v), "set 2");
TEST(vector_ref(VECTOR(v), (obj_t)0x333, 2), VECTOR(v), "set 2");
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        TEST(vector_insert(VECTOR(v), (obj_t)0x888, 3), VECTOR(v), "insert at
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                TEST(vector_insert(VECTOR(v), (obj_t)0x111, 1), NULL, "insert beyond
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       TEST(vector_dequeue(VECTOR(v)), 0x111, "getting from vector");
TEST(vector_dequeue(VECTOR(v)), 0x222, "getting from vector");
TEST(vector_dequeue(VECTOR(v)), 0x333, "getting from vector");
TEST(vector_dequeue(VECTOR(v)), 0x444, "getting from vector");
TEST(vector_dequeue(VECTOR(v)), NULL, "getting from empty vector");
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 print_vector(VECTOR(v));
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        TEST(vector_insert(VECTOR(v), (obj_t)0x999, 0), VECTOR(v), "insert at
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    TEST (vector_insert (VECTOR(v),
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 print_vector(VECTOR(v));
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 TEST(vector_insert(VECTOR(v),
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      TEST(vector_insert(VECTOR(v), (obj_t)0x222, 1), VECTOR(v), "insert at
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 \label{eq:TEST_vector_dequele} $$\operatorname{TEST}(\operatorname{vector_dequele}(\operatorname{VECTOR}(v)), 0x66, "getting TEST(\operatorname{vector_dequele}(\operatorname{VECTOR}(v)), 0x77, "getting Testing Testin
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   TEST(vector_remove(VECTOR(v), vector_index_of(VECTOR(v), (obj_t)0x55)),
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              print_vector(VECTOR(v));
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            print_vector(VECTOR(v));
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         print_vector(VECTOR(v));
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  vector_enqueue(VECTOR(v), (obj_t)0x444);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               vector_enqueue(VECTOR(v),
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        vector_enqueue(VECTOR(v), (obj_t)0x111);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     TEST(vector_clear(VECTOR(v)), VECTOR(v),
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    {\tt TEST(vector\_count(VECTOR(v)), 5, "count after remove bogus");}
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             TEST(vector_remove(VECTOR(v), vector_index_of(VECTOR(v),
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   \mathtt{TEST}(\mathtt{vector\_count}(\mathtt{VECTOR}(\mathtt{v})),
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      {\tt TEST(vector\_count(VECTOR(v)), CAPACITY, "full count = capacity");}
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  TEST(vector\_count(VECTOR(v)), 0, "count = 0");
                                                                                                                                                                                                                                                                                                                                                                                                                                            // v = 0x999 0x111 0x222 0x888
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       "remove bogus");
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    NULL,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                "remove from middle");
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               (obj_t)0x333);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          5, "count after remove");
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    (obj\_t) 0x111, 0), VECTOR(v), "insert at
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    (obj_t)0x222, 1), VECTOR(v),
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           "clear vector");
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              from vector");
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              from vector");
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           from vector");
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 from vector");
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 "insert at
```

```
TEST(vector_swap(VECTOR(v), 1, 2), VECTOR(v), "swap");
TEST(vector_ref(VECTOR(v), 2), 0x111, "ref 2 post swap");
TEST(vector_swap(VECTOR(v), 1, 2), VECTOR(v), "swap");
TEST(vector_ref(VECTOR(v), 2), 0x333, "ref 2 post swap");

// v = 0x999 0x111 0x333 0x888
TEST(vector_remove(VECTOR(v), 4), NULL, "remove beyond end");
TEST(vector_remove(VECTOR(v), 4), NULL, "remove middle");
TEST(vector_remove(VECTOR(v), 2), 0x333, "remove first");
TEST(vector_remove(VECTOR(v), 1), 0x888, "remove first");
TEST(vector_remove(VECTOR(v), 1), 0x888, "remove first and last");
```

#endif

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APPENDIX C ArborNet "BART" Code Listing

Following is the ArborNet C source code that is executed by the PIC16F84 "BART" radio processor on the Constellation board. More information on the ArborNet system can be found in Chapter 7.

File: bart.h

```
#define _BART_H
// -*- Mode: C++ -*-
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // For general public use.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          #nolist
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         #ifdef _BART_H
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                // Media Laboratory, MIT. Permission to use, copy, or modify this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // This distribution is approved by Walter Bender, Director of the
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           / Description: general system definitions for BART radio chip
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            / File:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            This MIT Media Laboratory project was sponsored by the Defense Advanced Research Projects Agency, Grant No. MOA972-99-1-0012. content of the information does not necessarily reflect the
                                                                                            or adapted as the basis of a commercial software or hardware
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                                                                                                                                                                                                                                                                                               copyright notice must be included.
                                                                                                                                                                                                                                                                                                                                                                                                                                            copyright notice and the original authors' names appear on all
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            bart.h
                                                                                                                                                                                                                                                                                      For any other uses of this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               All
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     The
```

```
#define ASSERT_READY(b)
#define READY_IS_ASSERTED()
                                                                                                                                                                                                                                                                                                                                                                                                                           struct PORT_B_MAP const PORT_B_RCV = \{0x0, 1, 0, 0, 0\}; struct PORT_B_MAP const PORT_B_RCV = \{0x0, 0, 0, 1, 1\};
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // TRIS bits for transmit mode (from host to PIC to radio)
struct PORT_A_MAP const PORT_A_XMT = {0xf, 1, 0, 0, 0};
struct PORT_B_MAP const PORT_B_XMT = {0xf, 0, 0, 1, 1};
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  struct PORT_A_MAP {
  int HDATA_LO:4;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // any purpose.
// warranty.
#define BIT_PERIOD
                            // With a 20 MHz crystal, one tic is .2 uSec, so the bit period // is 8.8 uSec, or 113.63 KBaud
                                                                                                                                       #byte PORT_B = 6
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             struct PORT_B_MAP {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      // I/O pin definitions
                                                                                   // The bit period for serial (radio) data, measured in TMRO tics
                                                                                                                                                                                                                                                                                                                                             // BART_READY is a low true signal
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // TRIS bits for receive mode (from radio to PIC to host
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         #byte PORT_A = 5
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  PORT B;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        PORT_A;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    boolean RCV_MODE;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              boolean RADIO XMT;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               boolean unused_a5;
boolean unused_a6;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        boolean HOST_CLK;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 boolean BART_READY;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        int HDATA_HI:4;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  boolean unused_a7;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     boolean RADIO_RCV;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   It is provided "as is" without express or implied
                                                                                                                                                                                                                                                          (!PORT_B.BART_READY)
                                                                                                                                                                                                                                                                                    PORT_B.BART_READY = !(b)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     // B0:3 high nibble of host data
// B4 serial data (to radio)
// B5 handshake (to host)
// B6 recv/xmit control (from host)
// B7 handshake (from host)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     // A0:3 low nibble of host data
// A4 serial data (from radio)
```

#endif #list

File: bart.c

```
typedef short int boolean;
                                                                                                                                                                                                                     #use fast_io(B)
                                                                                                                                                                                                                                                              #use fast_io(A)
// #define BLAT_STATE
                                                                                                                                                                                                                                                                                                                                                                // All timing is done with TMRO, so software delays aren't needed
// #use DELAY(clock=20000000)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        #fuses HS, WDT, NOPROTECT, PUT
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // run with watchdog timer ON so PIC will restart if it gets hung.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       #include <16F84.H>
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // For general public use
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // -*- Mode: C++ -*-
                                         // if defined, put state vars on parallel port
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // Media Laboratory, MIT.
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       File:
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          warranty.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    any purpose.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     position or the policy of the Government, and no official
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   bart.c
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    It is provided "as is" without express or implied
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          Permission to use, copy, or modify this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               All
```

```
// establishing sync between transmitters and receivers
#include "sync.c"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // managing serial I/O with the radio
#include "radio.c"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 #include "fifo.c"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              #include "codec.c"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        #include "radio.h"
#include "sync.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             #include "utils.h"
#include "bart.h"
                                                                                                                                                                                                                      void setup_transmit() {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 #include "host.c"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // Defines encode_nibble() and decode_nibble()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // keep track of how many times reset has been called.
// memory is not zeroed at reset.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         short int gXmtActive;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // gXmtActive is true as long as we're in transmit mode (RCV_MODE=0) // and there are more bits to be sent in the fifo. It will be set
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       #include
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                #include
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    #include "procregs.h"
// set up for receive mode
                                                                                                                                                                                                                                                                                                                                 // initialization and main code
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // globals
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           #include
                                                                                                                                                                                                                                                                           // set up for transmit mode
                                                                                                                                                                                                                                                                                                                                                               ^{\prime\prime} managing parallel I/O with the host
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // a simple FIFO for buffering data between host and radio
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // conversion between 4 bit decoded and 6 bit dc-balanced encoded
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     // to false after the last bit has ben transmitted
                                                                                                                                 set_tris_b(PORT_B_XMT);
HOST_SETUP_TX();
                                                                                                           RADIO_SETUP_TX();
                                                                                                                                                                                        set_tris_a(PORT_A_XMT);
                                                                                  FIFO_RESET();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       included files
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   gResetCount;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             "fifo.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  "host.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       Assumes
```

```
void setup_receive() {
  set_tris_a(poRT_A_RCV);
  set_tris_b(poRT_B_RCV);
  HOST_SETUP_RX();
  RADIO_SETUP_RX();
  FIFO_RESET();
                                                                                                                                                                                         void main() {
  int i;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               void blat_state() {
  output_high(PIN_B3);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      #ifndef BLAT_STATE
                                                                                                                                                                                                                                              // main()
                                                                                                                                                                                                                                                                                                                                                                                                      #endasm
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    #asm
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     #inline
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       #else
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        #define blat_state()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // blat_state() - put state vars on parallel port for debugging
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      #inline
                                                                                                                                                                                                                                                               #endif
                                                                     do {
                                                                                                                                     set_tris_a(PORT_A_XMT);
set_tris_b(PORT_B_XMT);
                                                                                                                                                                                                                                                                                                                                                                                   output_low(PIN_B3);
                                                                                                                                                                                                                                                                                                                                                                                                                                                     xorwf PORT_B, w andlw 0x07
                                                                                                                                                                                                                                                                                                                                                                                                                                    xorwf PORT_B, f
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          movf gHState, w
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              xorwf PORT_A, w andlw 0x0f
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                movf gRState, w
                                                                                       i = 30;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           xorwf PORT_A, f
                                                                                                     // this loop makes it obvious to a 'scope that we've reset.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // host state on high nibble
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // radio state on low nibble
              ASSERT_READY(1);
delay_cycles(43);
ASSERT_READY(0);
delay_cycles(43);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      /* nop */
```

```
} while (--i);
gResetCount++;

setup_counters(RTCC_INTERNAL, WDT_18MS);

while (1) {

// enter transmit mode, stay there until the host asserts RCV_MODE

// and fifo has finished transmitting its contents

setup_transmit();
gXmtActive = 1;
do {
    service_radio_xmt();
    while (gXmtActive);
} while (gXmtActive);

// enter receive mode, stay there until the host drops RCV_MODE

setup_receive();
do {
    service_radio_rcv();
    restart_wdt();
}
while (PORT_B.RCV_MODE);
}
```

File: codec.h

```
#ifdef _CODEC_H
// pattern is given.
                                                                                                                                                                                                                              int codec_encode(int nibble);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     #define DECODE_SYNCH
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   #define DECODE ILLEGAL 0x80
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     // two special values returned by codec_decode()
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // Convert binary nibble (in low order 4 bits of nibble) into 6 bit,
                                                                                                                                        // Convert DC balanced "hexlet" (in low order 6 bits of hexlet) into
                                                                                                                                                                                                                                                                                                                                                                                                                    // macro, as follows:
                                                                                                                                                                                                                                                                                                                                                                                                                                                         // DC balanced values. Values may be received using the W_RECV()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               / File:
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                                             four bit value (returned in W register). Returns DECODE_ILLEGAL for illegal 6 bit patterns, returns DECODE_SYNCH if a sync header
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               product without first obtaining appropriate licenses from MIT.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       copyright notice must be included.
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                                                                                                                                                                                                                                                                                                                         W_RECV(result);
                                                                                                                                                                                                                                                                                                                                                                       codec_encode(nibble);
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//
// Values may be fetched using the W_RECV() macro, as in:
// codec_decode(hexlet);
// W_RECV(result);
// if (result == DECODE_ILLEGAL) error();
//
int codec_decode(int hexlet);
#endif
#list
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File: codec.c

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#include "utils.h"
                                                                                                                                                                                                                                                                                  // TWO BIG WARNINGS:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               any purpose. It is provided "as is" without express or implied
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                                                                                                          [2] Make sure that codec_{de en}code is called AS A SUBROUTINE, via
                                                                                                                                                                                                                          [1] Make sure neither dispatch table crosses a page boundary
there are two or more subroutine calls in the program.)
                                                       CALL rather than GOTO.
                                                                                                                                                                  if so, you must use DISPATCH() rather than SHORT_DISPATCH().
                                                       (The CCS compiler will use CALL whenever
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#endasm
                                                                                                                                   int codec_decode(int hexlet) {
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                                                                                                                                                                             codec_decode(hexlet);
                                                                                                                                                         if (result == DECODE_ILLEGAL) error();
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// checked for underflow, as in !FIFO_IS_EMPTY(). Returns value in W,
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                                       // Fetch a byte from the fifo.
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                                                                                                                                                                                                                                                                                                                                           -*- Mode: C++ -*-
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 fifoPut;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 fifoLen;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         fifoGet;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             fifo.c
             Assumes caller has checked for overflow
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // # of byte stored in fifo
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  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                                   The
```

```
#endif
                                                                                                                                                                                                                                                                                                                                                                                                  void fifo_put(int &b) {
                                                                                                                                                                                                                                                                                                                                                                                                              #inline
            #endasm
                                                                                                              #asm
                                                                                                                                      void fifo_get() {
                                                                                                                                                                                                                                                                                                                                                              #ifdef DONT_BUM_CYCLES
                                                                                                                                                                                                                          #endif
                                                                                                                                                                                                                                      #endasm
                                                                                                                                                                                                                                                                                                                           #asm
                                                                                                                                                                                                                                                                                                                                      #else
                                                                                                                                                             // Returns value in W register.
                                                                                                                                                                          ^\prime/ fetch a byte from fifo. Assumes caller has checked for underflow.
                                                                                                                                                                                                                                                            movf
incf
addlw
movwf
movf
                                    movlw
andwf
                        movf
                                                                                     incf
                                                                                                movf
                                                             movwf
                                                                         addlw
                                                                                                                                                                                                             fifoPut &= FIFO_MASK;
                                                                                                                                                                                                                                                   movwf
                                                                                                                                                                                                                                                                                                                                                                          fifoLen++;
                                                                                                                                                                                                                                                                                                                                                                                      // if (fifoLen == FIFO_CAPACITY) return;
                                                                                                                          fifoLen--;
                                                                                                                                                                                                                                                                                                                                                  fifo[fifoPut++] = b;
                         fifoGet,F
                                                                                                                                                                                                                                                   INDF
                                                                                                                                                                                                                                                             b,W
                                                                                                                                                                                                                                                                                      fifo
                                                                                                                                                                                                                                                                                                 fifoPut,W
fifoPut,F
                                                               FSR
                                                                          fifo
                                                                                                                                                                                                                                                                           FSR
                                                 FIFO_MASK
                                                                                                  fifoGet,W
                                                                                    fifoGet,F
                        d* = m //
                                                // p = &fifo[fifoGet++]
// fifoGet &= FIFO_MASK
                                                                                                                                                                                                                                                                                                                                                                                      // overflow, sorry.
```

File: host.h

```
#list
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               #define _HOST_H
// -*- Mode: C++ -*-
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                #ifdef _HOST_H
#nolist
                               #endif
                                                                                                                                                                                      void service_host_rcv();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            #define HOST_SETUP_TX()
                                                                                                                void service_host_xmt();
                                                                                                                                                                                                                                                                                                                                                                                        #define HOST_SETUP_RX()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // warm reset code
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                #else
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                copyright notice must be included. For any other uses of this software, in original or modified form, including but not limited to distribution in whole or in part, specific prior permission must be obtained from MIT. These programs shall not be used, rewritten, or adapted as the basis of a commercial software or hardware
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   product without first obtaining appropriate licenses from MIT. MIT makes no representations about the suitability of this software for any purpose. It is provided "as is" without express or implied
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            Media Laboratory, MIT. Permission to use, copy, or modify this
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   warranty.
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 Copyright 2001 by the Massachusetts Institute of Technology. All
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                                                                                                                                                                                                                                                                                                ASSERT_READY(0)
                                                                                                                                                                                                                                                                                                                                                 gHState = SHR_A;
                                                                                                                                                                                                                                                                                                                                                                                                                                                              gHState = SHX_A;
ASSERT_READY(0)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     host.h
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 The
```

File: host.c

```
// -*- Mode: C++ -*-
                                                                                                                                                                                                                                             // Timing requirements:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      // FIFO for bytes and send them to the host via the parallel port
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // This file implements the following:
                                                                                                                                                                                                 Both service_host_rcv() and service_host_xmt() share processor
                                                                                                                                                                                                                                                                                                                                                                                                                                              In transmit mode (sending data to radio), monitor the parallel
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              Media Laboratory, MIT.
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                                                perturb the serial timing.
                                                                                                                                                cycles with the software UART defined in radio.c.
                                                                                                                                                                                                                                                                                                                                                                                              port for data transfers from the host and store incoming bytes
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      as they become available.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               warranty.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       product without first obtaining appropriate licenses from MIT. MIT makes no representations about the suitability of this software for any purpose. It is provided "as is" without express or implied
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should consume only a small fraction of BIT_PERIOD tics.
                                                                                                these routines must execute and return very quickly so as not to
                                                                                                                                                                                                                                                                                                                                                  in the software fifo as they are sent.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              void service host xmt();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       In receive mode (reading data from radio), monitor the software
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       void service_host_rcv();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    to distribution in whole or in part, specific prior permission must be obtained from MIT. These programs shall not be used, rewritten,
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                                                As a rule of thumb, these functions
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     For any other uses of this
                                                                                                                                                     Consequently,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         A11
```

```
goto shr_C
#define SHR_A 1
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              int
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          #include "host.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 #include "procregs.h"
#include "utils.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                        #endasm
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           #define SHR_C 0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        void service_host_rcv() {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       int
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // service_host_xmt() since the s
// transmitting at the same time.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // Variables can be safely shared between service_host_rcv() and
                                                                                                                                                                                                                                                                                                                                                                                                  shr B:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // dispatch) shaves off two critical cycles.
                                                                                                                                          shr_A:
} else {
                       // Announce readiness in BART_READY.
if (FIFO_IS_EMPTY()) {
   ASSERT_READY(0);
                                                                                                                                                                                                                                                                                                                                  if (PORT_B.HOST_CLK)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     SHORT_DISPATCH(gHState)
                                                                                                              // Wait for a byte to become available in the fifo
                                                                                                                                                                                                  return;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         transfers data from the FIFO to the parallel port.
                                                                                                                                                                                                                                                                                                                                                                   // Await HOST_CLOCK, then fetch a byte from the fifo
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    requires 25 cycles, leaving 44\text{-}25=19 cycles for this routine The odd ordering of the clauses (putting shr_B first after the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                End of Edit History
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        Called regularly when the radio is in receive mode, this routine
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                service_host_rcv()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     service_host_xmt() was getting stuck in stateD. fixed typo
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 08 Oct 2000: r@media.mit.edu
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          Edit History:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              service_host_xmt() since the system can't be receiving and
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  gHByteBuf;
                                                                                                                                                                                                                                                                                 W_RECV(gHByteBuf);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                               gHState = SHR_C;
                                                                                                                                                                                                                                                                                                                fifo_get();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            "bart.h"
                                                                                                                                                                                                                                                        // gHState was 2(B), now 0(C)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      // bart_ready <= fifo_state, advance if avail
// wait for HOST_CLOCK, pull data from FIFO</pre>
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // post data to port, await !HOST_CLOCK
                                                                                                                                                                                                                                                                               // fifo_get returns value in W
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 The caller
```

```
void service_host_xmt() {
"--
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           #endif // ifdef DONT_BUM_CYCLES
#endasm
                                                                                              #define SHX_A 0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            #asm
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // Output the byte to the host port, await !HOST_CLK #ifdef DONT_BUM_CYCLES PORT_A.HDATA_LO = gHByteBuf;
                                                                                                                                                                                                                    // Inform host if there's room in the FIFO by raising BART_RDY
// Await HOST_CLOCK, latch data on parallel port
// Store data in fifo, await !HOST_CLOCK
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                #ifndef BLAT_STATE
                                                                                                                                                                                                                                                                                              // Handle the host port in transmit mode.
                                                                                                                                                                                                                                                                                                                       // service_host_xmt()
                                                                                                                                                                                                                                                                                                                                              #endif // ifndef BLAT_STATE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            #else
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          xorwf PORT_B, f
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           swap(gHByteBuf);
PORT_B.HDATA_HI = gHByteBuf;
                                                                                                                     SHORT_DISPATCH(gHState)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                     if (!PORT_B.HOST_CLK) {
   gHState++;
   /
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              andlw 0x0f
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     xorwf PORT_B, w
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             movf gHByteBuf, w movwf PORT_A
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            return;
                                                                                                                                                                                                                                                                                                                                                                                                                        return;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                swapf gHByteBuf, w
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // the bits. hsnibble of PORT_A is either inputs (A4) or
// unused. cycle shaving to the max...
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // xorwf PORT_A, f
// super big cheeze hack: lsnibble of PORT_A is where we put
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // movf gHByteBuf, w
// xorwf PORT_A, w
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // This code requires that HDATA_LO and HDATA_HI appear at the
// low four bits of PORT_A and PORT_B respectively.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                // andlw 0x0f
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        andlw 0x07
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      gHState++;
                                          goto shx_B
                    goto shx_C
                                                                   goto shx_A
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  ASSERT_READY(1);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // gHState was 0(C), now 1(A)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // ### leave B3 for debugging
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // gHState = 0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // gHState was 1(A), now 2(B)
                    // if room in fifo, assert ready
// await host clock, latch data
// store in fifo, await !host clock
                                                                                                                                                                                                                                                                                            Loop as follows:
```

```
// on parallel port
if (PORT_B.HOST_CLK) {
#ifdef DONT_BUM_CYCLES
gHBytcBuf = PORT_B.HDATA_HI;
                                                                                                                                                                                                                                                                      #endif
                                                                                                                                                                                                                                                                                                                                                                                                         #else
                                                                                                                                                        shx_C:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  shx_B:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           shx_A:
   if (!FIFO_IS_FULL()) {
                                                                                 // host clock to drop before going to next state.
if (!PORT_B.HOST_CLK) {
return;
                                                                                                                                                                                                   return;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // wait for host clock to go true before latching data
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   return;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              gHState++;
} else {
                                                                                                                                  '/ store the byte fetched in the previous state, wait for
                                        gHState = SHX_A;
                                                                                                                                                                                                                                                                                                                                 // This code requires that HDATA_IO and HDATA_HI appear at the
// low four bits of PORT_A and PORT_B respectively.
gHByteBuf = (int *)PORT_B & OxOf;
                                                                                                                                                                                                                                                                                                                                                                                                                       ghbyteBuf |= PORT_A.HDATA_LO;
                                                               fifo_put(gHByteBuf);
                                                                                                                                                                                                                                            gHState++;
                                                                                                                                                                                                                                                                                         gHByteBuf |= (int *)PORT_A & 0x0f;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          ASSERT_READY(1);
                                                                                                                                                                                                                                                                                                               swap (gHByteBuf);
                                                                                                                                                                                                                                                                                                                                                                                                                                                 swap (gHByteBuf);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         ASSERT_READY(0);
```

File: procregs.h

```
#byte
                                                                                                                                                                                                                                                                                                       #byte
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     // PCM-C readable register definitions for
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  #define
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               #nolist
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                                                                                                                                                                                                                 struct
                                                                                                                                                                                                                                                                                                                                                                                                                           // only for the PIC16F84 and for the 12C672
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // Media Laboratory, MIT.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // This distribution is approved by Walter Bender, Director of the
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      // File: procregs.h
// Description: C definitions of selected PIC processor registers
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    #define _PROCREGS_H
// -*- Mode: C++ -*-
                           short
                                                         short
                                                                                        short
                                                                                                                      short
                                                                                                                                                  short int DC;
                                                                                                                                                                                   short
short
                                                                                                                                                                                                                                                                                                                                                                                                                                                         general PICs. This version is tailored
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t int RPO;
t int RP1;
                                                       int
int
                                                                                                                                                                                int C;
                                                                                                                                                                                                                                                                         INDF
TMR0
PCL
                        Z;
PD_L;
TO_L;
RPO;
                                                                                                                                                                                                                                                                         = 0x00
= 0x01
= 0x02
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          Permission to use, copy, or modify this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           The
```

```
#byte
#list
       #endif
                       #byte
                                                                                                           struct
                                                                                                                  #byte
                                                                                                                                   #byte
                                                                                                                                            #byte
                                                                                                                                                   #byte
                                                        short int TOIF;
short int RBIE;
short int INTE;
short int TOIE;
                                short int GIE;
INTCON;
                                                                                         short
                                                                                                 short
                                                                                                                                                             STATUS;
                                                short int PEIE;
                                                                                                                                                                     short int IRP;
                                                                                          int
                                                                                                  int
                        INTCON
                                                                                                                  PCLATH
                                                                                                                           PORTB
                                                                                                                                   PORTA
                                                                                                                                            FSR
                                                                                                                                                     STATUS
                                                                                  RBIF;
INTF;
TOIF;
                        = 0x0B
                                                                                                                    II
                                                                                                                                                    = 0x03
                                                                                                                                    = 0x05
                                                                                                                                            = 0x04
                                                                                                                   0x0A
                                                                                                                           0x06
```

File: radio.h

```
#define RADIO_SETUP_TX()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             #ifdef _RADIO_H
// header.
                                                                                                                          #define SYNC_TIMEOUT
                                                                                                                                                                                                                                                 //\ {
m number} of bit periods to try for a sync header before
                                                                                                                                                                                                                                                                                                                                                                                                                                                                 #define RADIO_SETUP_RX()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // warm reset code
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              #define _RADIO_H
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          #nolist
                                          // number of 6 bit sync chars to send when transmitting
                                                                                                                                                             // 10 periods
                                                                                                                                                                                                           // timing out. each sync header is 6 bits long; try for
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // Copyright 2001 by the Massachusetts Institute of Technology.
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                                                                                                                                                                                                                                                                                                                                                                                PORT_B.RADIO_XMT = 0
                                                                                                                                                                                                                                                                                                                                                                                                                              gRState = SRR_SYNC;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         gRState = 0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       radio.h
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       The
```

```
#define SYNC_HDR_LENGTH 6 // in 6-bit "hexlets"
// in receive mode, monitor RADIO_RCV line, read encoded serial
// data, decode, store in FIFO.
#inline
void service_radio_rcv();
// in transmit mode, fetch bytes from FIFO, encode and send as
// serial data on RADIO_XMT line
#inline
void service_radio_xmt();
#endif
```

File: radio.c

#list

```
// NOTE: send/receive MSB first
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      Media Laboratory, MIT. Permission to use, copy, or modify this software and its documentation for educational and research
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             -*- Mode: C++ -*-
                                                                                                                                                                                                                                                                                                                                                                                  These programs shall not be used, rewritten,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         For any other uses of this
```

periods where service_radio_rcv() doesn't have other time consuming

The servicing of the host parallel port happens only in those bit

```
int
                              #define SRR_SYNC 0
                                                                                                             void service_radio_rcv() {
                                                                                                                                                                                                                          // the initial state, fewer than BIT_PERIOD cycles may elapse between
// calls to service_radio_rcv(), or data will be lost.
                                                                                                                                                                                                                                                                                                                                                                                           // In the initial state, it will search for a sync pattern on the // radio's receive line. Once it establishes sync, it will read
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         void _put_radio_bit();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           void _get_radio_bit();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            #inline
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            short int gIsPacketStart;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           #define LEADER_CHAR 'A'
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               int
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // transmitting at the same time.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       #include "fifo.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        #include
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    #include "utils.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                #include
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            #include
                                                                                                                                                                                                                                                                                                                                                                 // serial bits, decode their 6 bit form into a 4 bit nibble, assemble
                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // service_radio_rcv() - in receive mode, monitor RADIO_RCV line,
// read encoded serial data, decode and store in FIFO.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // Variables can be safely shared between service_radio_rcv() and
                                                                                                                                                                                                                                                                                // This routine essentially implements a software UART.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // Every packet has leader char
                                                                                                                                                                                                                                                                                                                                        pairs of nibbles into bytes, and store the bytes in the FIFO
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          the host. This shou handled by the host.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           Upon transmission, BART generates a leader char at the start of each packet. Upon reception, if the first non-sync char isn't a
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              06 Nov 2000 r@media.mit.edu
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 operations, such as transfers to the fifo or encoding and decoding six bit values. In short, timing is critical!
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   leader char, BART reverts to searching for sync without troubling the host. This should cut down on the number of spurious packets
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   service_radio_xmt() since the system can't be receiving and
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   In our noisy environment, BART detects many false sync
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       gRBytBuf;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    gRState;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        gRSerBuf;
                                                       SHORT_DISPATCH(gRState)
goto srr_sync
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      "sync.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           "procregs.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            "radio.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       immediately following the synch header
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // six bit serial shift register
// holding register for decoded byte
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // true when seeking leader char
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // got any better ideas?
  // establish sync, sample b11 (msb)
                                                                                                                                                                                                                                                                                     In all but
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   #endasm
                                                                                                                                                                                                                                                                                                                                                                      srr b04:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        srr_sync:
                                                                                                                                                                                                                                                                                     srr_b01:
                                                                                                                                                                                                                                                                                                                 srr b02:
                                                                                                                                                                                                                                                                                                                                          srr_b03:
                                                                                                                                                                                                                                                                                                                                                                                                srr_b05:
                                                                                                                                                                                                                                                                                                                                                                                                                                                        srr_b07:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    srr b08:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             srr_b09:
                                                                                                                                                                                                                                                                                                                                                                                                                            // bo6
                                                                                      return;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        goto
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          goto
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            goto
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      goto
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  goto
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               goto
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    goto
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                goto
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              goto
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          goto
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      goto
```

```
#define SRR_B11_INITIAL 1
goto srr_b11_initial
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             #define SRR_B09 3
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            #define SRR_B10_INITIAL 2
                                                                                                                                                                                          srr bl1 store:
                                                                                                                                                                                                                                                                                                                                                                                                                                                   srr_b10_initial:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                          srr_b11_initial:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // midpoint of each received bit. Fetch the first bit (b11, MSB
// first) before returning.
gRState = SRR_B11_INITIAL; // next: srr_b10
                                                                                                                                                                                                               // b00 below
                                                                                              gRState++;
                                                                                                               service_host_rcv();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             gIsPacketStart = 1;
// sample bit 6 of input stream.
                                                                                                                                                                // sample a bit and service the parallel port
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     // --v-- fall through...
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   if (!find_sync(SYNC_TIMEOUT)) {
                                                                                                                                           _get_radio_bit();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // deferred.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // routines in service_radio_rcv() which all complete in
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               / found sync.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       / time to complete.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               / less than 44 tics, this one might take a relatively long
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              / Here to establish initial sync. Note that unlike other
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  goto srr_b10_initial
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                return;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        gRState = SRR_SYNC;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // didn't find sync.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     goto srr_b09
                                                                                                                                                                                                                                                                                                                                                         below
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    srr_b10_store
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          srr_b00
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                srr_b02
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        srr_b03
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    srr
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      srr_b07
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                srr_b08
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  srr_b11_store
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 srr_b01
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         srr_b05
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              srr_b06
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      b04
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 From here on, TMR0 rolling over (T0IF) marks
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       During this time, host transfers are
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             Try again at next call to service_radio_rcv()
Having accumulated the first
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // b09 & service host port
// b08 & service host port
// b06 & store high nibble
// b05 & service host port
// b04 & service host port
// b03 & service host port
// b02 & service host port
// b01 & service host port
// b01 & service host port
// b11 & service host port
// b11 & service host port
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // b10 & service host port
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // bll & service host port
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            to
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            fifo
```

```
#endasm
                                                                                                                                                          srr_b10_store:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            srr_b00:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         swap(gRBytBuf);
  gRState = SRR_B09;
                         _get_radio_bit();
fifo_put(gRBytBuf);
                                                                                                                                                                                                           return;
                                                                                                                                                                                                                                  gRState++;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    iorwf gRBytBuf, f
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // gRBytBuf |= codec_decode(gRSerBuf);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             codec_decode(gRSerBuf);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // ## get sync filler here.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             return;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 W_RECV(gRBytBuf);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   codec_decode(gRSerBuf);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // 6 bit packet, decode into 4 bit and store in accum byte.
                                                                             // service_host_rcv() is called every other tic.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // in the W register.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // After the call to codec_decode(), the decoded 4 bit nibble is
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // ## sync filler for the first nibble, so we don't expect to
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // ## Note that we don't check for sync or illegal bit patterns
// ## here - if we get either, gRBytBuf is blithely clobbered.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // gRBytBuf = codec_decode(gRSerBuf);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // Following the call to codec_decode(), the decoded 4 bit nibble
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               _get_radio_bit();
                                                                                                      // the fifo.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   _get_radio_bit();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            ^{\prime /} ## On the other hand, the sending code will only generate
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // merge with gRBytBuf
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                ^{\prime}/ sample bit 00 (LSB), decode accumulated 6 bits to 4 bit,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // is in the W register.
                                                                                                                                / sample bit 10, store byte previously accumulated
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        else
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          gRState++;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             gRState = SRR_B11_INITIAL;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                if (gIsPacketStart) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         (gRBytBuf
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          if (gRBytBuf == LEADER_CHAR) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // in srr_b06, sync "nibbles" were stripped out. Arrive here
// after finding the first non-sync character. If it was a
// bona-fide leader char, accept it and start reading the rest
// of the packet. If not, start all over again looking for
                                                                                                                                                                                                                                                                                                                                                                                           else
                                                                                                                                                                                                                                                                                                                                       gRState =
                                                                                                                                                                                                                                                                                                                                                                                                                  return;
                                                                                                                                                                                                                                                                                                                                                                                                                                            gIsPacketStart = 0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                     gRState = SRR_B11_INITIAL;
                                                                                                                                                                                                                                                                                                                return;
                                                                                                                                                                                                                                                                                                                                                                 // wasn't
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    sync.
                                                                                                  : 10, store byte previously accumulated (gRBytBuf) in We wait until bit 10 (rather than bit 11) so that the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       == DECODE_SYNCH) {
                                                                                                                                                                                                                                                                                                                                       SRR_SYNC;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            The following IORWF is equivalent to:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  Do the equivalent to:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // make room in lsnibble
                                                                                                                                                                                                                                  // sample b11 and store...
                                                                                                                                                                                                                                                                                                                                                                                                                                                              // strip sync bytes
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // strip sync bytes
                                                                                                                                                                                                                                                                                                                                                                                                                  #define SYNC_B01 5
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       #inline
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     #inline
                                                                                                                                                                                                                                                                                                                                       #define SEND_B11 7
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             goto sync_b04
#define SYNC_B03 3
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     #define SYNC_B05 1
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                // an 8 bit byte
goto send_b02
goto send_b01
goto send_b00
                                                                                                                                                                                                           goto
                                                                                                                                                                                                                                  goto
                                                                                                                                                                                                                                                            goto
                                                                                                                                                                                                                                                                                                                goto send_b11
                                                                                                                                                                                                                                                                                                                                                                                                                                                                     goto sync_b03
                                                                          goto send_b03
                                                                                                                                                                                    goto
                                                                                                                                                                                                                                                                                    goto send_b10
                                                                                                                                                                                                                                                                                                                                                                 goto sync_b00
                                                                                                                                                                                                                                                                                                                                                                                        goto sync_b01
                                                                                                                                                                                                                                                                                                                                                                                                                                         goto sync_b02
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            goto sync_b05
                                                                                                                                                          goto
                                                                                                                                                          send_b05
                                                                                                                                                                                    send b06
                                                                                                                                                                                                           send_b07
                                                                                                                                                                                                                                     send b08
                                                                                                                                                                                                                                                               send b09
```

```
goto send_b04
#define SEND_B03 15
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   void _get_radio_bit() {
   AWAIT_TMR0();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 #define AWAIT_START
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 void service_radio_xmt() {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               #define SYNC_CHAR 0b11100000
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                // ever runs dry, send sync chars until more data is available.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // SYNC_CHAR defines the six bit sync header char, left justified in
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // the LSB of the serial buffer. Update TMR0 before returning.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // output_low(PIN_B3);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        SHORT_DISPATCH(gRState)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   Send a stream of sync chars (sync_b05-b00). Thereafte sending bits from the fifo (send_b11-b00), MSB first.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        Serial Transmit (from FIFO to Radio)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           Wait for TMR0 to roll over, shift the radio serial port into
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             Initially, wait for a byte to appear in the fifo (await_start)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             goto await_start
                                                                                                // s=08 send bit 1
// s=19 send bit 0
// s=10 send bit 0
// s=11 send bit 0
// s=12 send bit 0
// s=13 send bit 0
// s=18 send bit 00 (lsb), encode high nibble
                  // s=15 send bit (
// s=16 send bit (
// s=17 send bit (
                                                                                                                                                                                                                                                                                         // s=05
// s=06
                                                                                                                                                                                                                                                 // s=07 send bit 11 (msb), service host
                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // s=00 loop until at least one byte in fifo
                                                                                                                                                                                                                                                                                                                                                    // s=03 send sync bit // s=04 send sync bit
                                                                                                                                                                                                                                                                                                                                                                                                                // s=01 send sync bit 5, // s=02 send sync bit 4
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // ## debug
                                                                                                                                                                                                                                                                                           send sync bit 1, send sync bit 0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          Thereafter, start
               03, service ......
02, fetch byte from fifo
02 host port
                                                                                                                                                                08,
                                                                                                                                                                                                            09,
                                                                                                      04,
                                                                                                                        05,
                                                                                                                                             06,
                                                                                                                                                                                                                             service host port
                                                                                                      service host port
                                                                                                                        service host port
                                                                                                                                               encode low nibble
                                                                                                                                                                  service host port
                                                                                                                                                                                     service host port
                                                                                                                                                                                                            service host
                                                                                                                                                                                                                                                                                                                                                       νν
                                                                                                                                                                                                                                                                                                                                                                            service host
                                                                                                                                                                                                                                                                                                                                                                                                                                       service
                                                                                                                                                                                                                                                                                                                service host port
                                                                                                                                                                                                                                                                                                                                                       service
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       If the fifo
                                                                                                                                                                                                                                                                                                                                                     host
                                                                                                                                                                                                                                                                                                                                                                                                                                       host port
                                                                                                                                                                                                          port
                                                                                                                                                                                                                                                                                                                                                                        port
                                                                                                                                                                                                                                                                                                                                                       port
                                                                                                                                                                                                                                                 port
```

#endasm

return;

```
_put_radio_bit();
#ifdef DONT_BUM_CYCLES
if (--gRBytBuf) {
#endasm
                                                                                                               #asm
                                                                                                                                   #else
                                                                                                                                                                                                                                                                                                                                                                                                                          sync_b04:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              send_b01:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    send_b03:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        send_b04:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               send_b05:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     send_b07:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         send_b08:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                send_b09:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      send_b10:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            send_b11:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   sync_b01:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       sync_b02:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           sync_b03:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  sync_b05:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              await_start:
                      movwf gRState
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       gRState++;
                                            movlw SYNC_B03
                                                              decfsz gRBytBuf, f
                                                                                     movlw SEND_B03
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               service_host_xmt();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    service_host_xmt();
if (PORT_B.RCV_MODE) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 gIsPacketStart = 1;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                        return;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     _put_radio_bit();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            if (!FIFO_IS_EMPTY()) {
   gRBytBuf = SYNC_HDR_LENGTH; // # of sync nibbles to send
   gRSerBuf = SYNC_CHAR; // set up char to be sent
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // wait for first byte to appear in the fifo
                                                                                                                                                                                                  gRState = SYNC_B03;
} else {
                                                                                                                                                                                                                                                                                                                                                         // send sync bit 04 and use gRBytBuf to decide whether to keep
// sending synch chars (sync_b03) or to switch to the mainstream
// code (send_b03). By switching to mainstream code, the final
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            return;
                                                                                                                                                                                                                                                                                                                // will be fetched from the FIFO, encoded and sent
                                                                                                                                                                                                                                                                                                                                    // 3 bits of the synch char will be sent, but the next byte
                                                                                                                                                                            gRState = SEND_B03
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     gRState++;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         SET_IMRO(BIT_PERIOD);
// from here on, TMRO marks onset of each bit period, honored by
// _put_radio_bit()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        // host is requesting receive mode. Quit now gXmtActive = 0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        return;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // put next msbit of gRSerBuf
// service parallel port
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // send sync 05
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // set up char to be sent
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // service parallel port
```

```
#endif
send b00:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              send_b02:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     send_b06:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          sync_b00:
                                                                                                                                    W_RECV(gRSerBuf);
                                                                                                                                                                                swap(gRBytBuf);
                                                                                                                                                                                                                                                                                                                      gRState++;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                gRState++;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     W_RECV(gRSerBuf);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                gRSerBuf = SYNC_CHAR;
gRState = SYNC_B05;
return;
                                                                                                             gRState = SEND_B11;
                                                                                                                                                             codec_encode(gRBytBuf);
                                                                                                                                                                                                                             // send bit 00 and encode the high nibble of the next byte
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              if (FIFO_IS_EMPTY()) {
   gRBytBuf = 1;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              codec_encode(gRBytBuf);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                swap(gRBytBuf);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              _put_radio_bit();
if (PORT_B.RCV_MODE && FIFO_IS_EMPTY()) {
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       return;
                                                                                           return;
                                                                                                                                                                                                                                                                                                  return;
                                                                                                                                                                                                                                                                                                                                                                                                                                                       if (gIsPacketStart) {
   // the very first char in the packet is the leader char
   gRBytBuf = LEADER_CHAR;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // is empty, send a synch char after sending bit 0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           return;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // send bit 06 and decode the low nibble of gRBytBuf
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // sync char
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // send bit 02 and fetch the next byte from the fifo. If the fifo
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       _put_radio_bit();
                                                                                                                                                                                                       _put_radio_bit();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         _put_radio_bit();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // put the last bit of gRSerBuf set state to send_b05 to send another
                                                                                                                                                                                                                                                                                                                                                                                                              gIsPacketStart = \overline{0}; else {
                                                                                                                                                                                                                                                                                                                                                              W_RECV(gRBytBuf);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           return;
                                                                                                                                                                                                                                                                                                                                                                                         fifo_get();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    return;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         gRState = SYNC_B01;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              gXmtActive = 0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     // game over.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // host is requesting receive mode and the fifo has drained
                                                                                                                                                                                                                                                                                                                                                                // fifo_get() returns val in
                                                                                                                                                                                                                                                                                                                      // next state = send_b01
                                                                                                                                                           // encode high nibble of gRBytBuf
// into 6 bit value
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                // next state = send_b05
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // encode low nibble of gRBytBuf
// into 6 bit value
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // recharge gRSerBuf with
                                                                                                                                                                                                                                                                                                                                                                    Σ
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              sync
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                char
```

```
// Wait for TMR0 to roll over, shift out the MSB of the serial buffer // (gRSerBuf) and write it to the radio port. Update TWR0 before // returning. Note that gRSerBuf is not only shifted, but in the #asm // code, may accumulate garbage in its right half.

#inline void _put radio_bit() {
   AWAIT_TMR0();
   AWAIT_TMR0();
   #else #asm
   output_bit(shift_left(&gRSerBuf, 1, 0));
##asm
   rlf gRSerBuf, f
   btfss STATUS.C
   bcf PORT_B.RADIO_XMT
   btfsc STATUS.C
   bsf PORT_B.RADIO_XMT
   befsc STATUS.C
   bsf PORT_B.RADIO_XMT
#endasm
#endif
UPDATE_TMR0(BIT_PERIOD);
```

File: sync.h

```
#list
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       #define _SYNC_H
// -*- Mode: C++ -*-
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               #ifdef _SYNC_H
#nolist
                                     #endif
                                                                                                                                                                                                // Try for n bit periods to find a sync header. If found, try to
// establish bit level sync. Returns 1 with TMRO primed to roll of
// in the middle of the first bit period, returns 0 otherwise.
                                                                                                                                                                                                                                                                                                                                                                     void putnibble(int nibble);
                                                                                                                                                                                                                                                                                                                                                                                                               void puthexlet(int hexlet);
                                                                                                                                                                                                                                                                                                                                                                                                                                                     void send_sync(int n);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       // warranty.
                                                                                                                 int find_sync(int n);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           // be obtained from MIT.
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              Description: establish byte and bit level synch with radio
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         any purpose.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        copyright notice must be included.
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   This MIT Media Laboratory project was sponsored by the Defense
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           Copyright 2001 by the Massachusetts Institute of Technology. All
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        endorsement should be inferred.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    sync.h
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 It is provided "as is" without express or implied
                                                                                                                                                                                                                                         Returns 1 with TMR0 primed to roll over
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    For any other uses of this
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 The
```

File: sync.c

```
// middle of the pattern.
                                                                                                                                           // Try to establish sync. If no SYNC_HEADER pattern is discovered // within N bit periods, the routine returns 0 to indicate failure.
                                                                                                                                                                                                                                                                                                    // receiving sync
                                                                                                                                                                                                                                                                                                                                                      // Each transmitted packet starts with a sync header, which is // a string of sync header characters. Each sync header char
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // Generating and detecting sync.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // a 50% DC balance and a single low-to-high transition in the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // The advantage of this particular pattern is that it features
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 // is 111000, that is, three bit periods on and three off.
                                                                                              If a sync header is found, the routine has established byte level
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                Media Laboratory, MIT.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               Description: generate and detect radio packet sync
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          File:
                                             synch, but not fine-grained bit level sync. It then spends
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deterministic amount of time (to be documented :) adjusting the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            to distribution in whole or in part, specific prior permission must be obtained from MIT. These programs shall not be used, rewritten,
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            Permission to use, copy, or modify this
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```

```
#define PRE_SYNC 0b00011100
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // from the onset of the next SYNC_HEADER.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                // when timing is between BIT_PERIOD and 2*BIT_PERIOD tics
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         // This is the 8 bit pattern that will be accumulated in tmp
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 int find_sync(int n) {
                                                                                                                                                                                                                                                                                                                                                                                      do
                                                                                                                                                                                                                                                                                                                                                                                                      tmp = 0;
// output_high(PIN_B3);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   // phase 1: Establish byte level synchronization by shifting in bits // until SYNCH_HEADER is detected (or until we exceed our alloted // number of bit cell times).
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               int tmp, i;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             SET_TMR0 (BIT_PERIOD);
// SYNC_HEADER frame:
                                                                    // At this point, the picture looks like this.
                                                                                                                                                                              } while (tmp != PRE SYNC);
                                        // sampled as early as 2*BIT_PERIOD before the onset of the next
                                                                                                                                         // output_low(PIN_B3);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       a register. When the bit pattern 00011100 is detected, then the header is assumed to fall as follows:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       from LSB first. One bit period is 44 clock tics long.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   The {\tt SYNC\_HEADER} is a rectangular wave, three bit periods high followed by three bit periods low, or 0x0f when read
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             Upon success, find sync() will return 1 and TMRO will be set up to roll over in the middle of the first bit period of the next "hexlet" (a six bit nibble).
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          bit level sync
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         find_sync() samples once every 44 tics, shifting received bits into
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           Theory:
                                                                                                                                                                                                                                                UPDATE_TMR0 (BIT_PERIOD);
                                                                                                                                                                                                                                                                            SHIFT_BIT_LEFT(tmp, PORT_A.RADIO_RCV);
                                                                                                                                                                                                           if (!--n) return 0;
                                                                                                                                                                                                                                                                                                                  AWAIT_TMRO();
                                                                                                                                                                                                                                                                                                                                                    restart_wdt();
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   < 44 tics
                                                                                                                                                                                                              // timed out
                                                                                                                                                                                                                                                                                                                                                                                                                      1
                                                                                                                                                                                                                                                                                                                                                                                                                   ## debugging
                                                                          B0 may have been
```

```
btfsc PORT_A.RADIO_RCV
goto found
             btfsc PORT_A.RADIO_RCV
                            goto found
                                         btfsc PORT_A.RADIO_RCV
                                                         goto found
                                                                      btfsc PORT_A.RADIO_RCV
                                                                                       goto found
                                                                                                   btfsc PORT_A.RADIO_RCV
                                                                                                                    goto found
                                                                                                                               btfsc PORT_A.RADIO_RCV
                                                                                                                                               goto found
                                                                                                                                                            btfsc PORT_A.RADIO_RCV
                                                                                                                                                                            goto early
                                                                                                                                                                                          btfsc PORT_A.RADIO_RCV
                                                                                                                                                                                                        goto early
                                                                                                                                                                                                                    btfsc PORT_A.RADIO_RCV
                                                                                                                                                                                                                                      goto early
                                                                                                                                                                                                                                                                 goto early
                                                                                                                                                                                                                                                                              btfsc PORT_A.RADIO_RCV
                                                                                                                                                                                                                                                                                              goto early
                                                                                                                                                                                                                                                                                                          btfsc PORT_A.RADIO_RCV
                                                                                                                                                                                                                                                                                                                         goto early
                                                                                                                                                                                                                                                                                                                                      btfsc PORT_A.RADIO_RCV
                                                                                                                                                                                                                                                                                                                                                     goto early
                                                                                                                                                                                                                                                                                                                                                                    btfsc PORT_A.RADIO_RCV
                                                                                                                                                                                                                                                                                                                                                                                  goto early
                                                                                                                                                                                                                                                                                                                                                                                              btfsc PORT_A.RADIO_RCV
                                                                                                                                                                                                                                                                                                                                                                                                                goto early
                                                                                                                                                                                                                                                                                                                                                                                                                            btfsc PORT_A.RADIO_RCV
                                                                                                                                                                                                                                                                                                                                                                                                                                            goto early
                                                                                                                                                                                                                                                                                                                                                                                                                                                         btfsc PORT_A.RADIO_RCV
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   All that's left to do is to look for the low-to-high transition that marks the next sync frame, which is expected no sooner than BIT_PERIOD-DLY and no later than 2*BIT_PERIOD-DLY cycles from now
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             At this point, DLY cycles have elapsed since sampling B0. So if B0 was sampled early, the onset of the next synch frame will be in 2 * BIT_PERIOD - DLY sample hence. If B0 was sampled late, the onset of the next frame will be BIT_PERIOD - DLY cycles from
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            minimum of 44-DLY cycles and a maximum of 88-DLY.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               DLY measured to be 25, so min = 19, max = 63.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           At 44 cycles per bit period, we expect the signal to remain low a
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               or as late as 1*BIT_PERIOD tics before the onset:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  The following code is written in assembly to guarantee the cycle
 onset
                                                                                                                                                                                                                                                                                                                                                        #endasm
                                                                                                                                                                                                                                                                  found:
                                                                                                                                                                                                                                                                                                             late:
                                                                                                                                                                                                                                                                                                                         early:
                                                                                                                                                                                                                                                                                              return 0;
                                                                     SET_TMR0((BIT_PERIOD/2)-6);
// output_low(PIN_B3);
                                                                                                                                                                                                                                                                                                                                                                     goto late
                                                                                                                                                                                                                                                                                                                                                                                    goto found
                                                          return 1;
                                                                                                                                // ## prepare for the bit, this routine could be modified to detect
// ## the middle of the SYNC_HEADER rather than the end (the falling
// ## edge rather than the rising edge), and set TMRO to fire in
// ## (3.5 * BIT_PERIOD - 6) rather than (0.5 * BIT_PERIOD - 6)
                                                                                                                                                                                                                                  // Arrive here within 5 (min) to 7 (max) cycles of RADIO_RCV going
// true. Assume it was 6, set TMRO to roll over (BIT_PERIOD/2)-6
                                                                                                                                                                                                                                                                                                                                                                                                btfsc PORT_A.RADIO_RCV
                                                                                                                                                                                                                                                                                                                                                                                                                goto found
                                                                                                                                                                                                                                                                                                                                                                                                                            btfsc_PORT_A.RADIO_RCV
                                                                                                                                                                                                                                                                                                                                                                                                                                            goto found
                                                                                                                                                                                                                                                                                                                                                                                                                                                            btfsc PORT
                                                                                                                                                                                                                                                                                                                                                                                                                                                                         goto found
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        btfsc PORT
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       goto found
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     btfsc PORT
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   goto found
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                btfsc PORT_A.RADIO_RCV
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                goto found
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              btfsc PORT_
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            goto found
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        btfsc PORT_A.RADIO_RCV
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         goto found
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       btfsc PORT
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      goto found
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   btfsc PORT_
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  goto found
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 btfsc PORT
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             goto found
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          btfsc PORT_A.RADIO_RCV
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          goto found
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        btfsc PORT_A.RADIO_RCV
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      goto found
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    btfsc PORT_A.RADIO_RCV
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   goto found
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                btfsc PORT_A.RADIO_RCV
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 goto found
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            btfsc PORT_A.RADIO_RCV
                                                                                                    // output_high(PIN_B3);
                                                                                                                                                                                        ## NB: If this doesn't leave enough time in the caller's code to
                                                                                                                                                                                                                      cycles from now
                                                                                                                               edge rather than the rising edge), and set TMR0 to fire in (3.5 * BIT_PERIOD - 6) rather than (0.5 * BIT_PERIOD - 6)
                                                                                                                                                                                                                                                                                                                                                                                                                                                         A.RADIO_RCV
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               _A.RADIO_RCV
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             _A.RADIO_RCV
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     _A.RADIO_RCV
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   _A.RADIO_RCV
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           _A.RADIO_RCV
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      A.RADIO_RCV
                                                                                                                                                                                                                                                                                                                                                             // 32
// 33
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// 63
// expected a transition bit by now
                                                                         // ###
                                                                                                   // ###
```

File: utils.h

```
#include "procregs.h"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  #define _UTILS_H
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           #nolist
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         #ifdef _UTILS_H
                                                                                                                                                                                                                                                           #define DISPATCH(offset)
                                                                                                                                                                                                                                                                                                                        // Efficient dispatch table.
// Offset is clobbered. Must
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              // For general public use
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            // Copyright 2001 by the Massachusetts Institute of Technology.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // Description: generally useful code hacks for the PIC
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // File:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          / -*- Mode: C++
                                                                movwf PCLATH
                                                                                                                             btfsc STATUS.C
                                                                                                                                                          movphw jmptbl
                                                                                                                                                                                             addwf offset,f
                                                                                                                                                                                                                           movplw jmptbl
     movwf PCL
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    software and its documentation for educational and research
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 Media Laboratory, MIT.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 This distribution is approved by Walter Bender, Director of the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              product without first obtaining appropriate licenses from MIT. MIT makes no representations about the suitability of this software for any purpose. It is provided "as is" without express or implied
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            rights reserved
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 or adapted as the basis of a commercial software or hardware
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        to distribution in whole or in part, specific prior permission must be obtained from MIT. These programs shall not be used, rewritten,
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                                                                                             addlw 1
                             offset, w
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          utils.h
                                                                                                                                                                                                                                                                                                                           Must be inside #asm context
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 Permission to use, copy, or modify this
                                                                                                                                                                                                                                                                                                                                                  Takes 11 cycles (including goto...)
/* w = offset
/* pcl = w
                                                             /* pclath = w
                                                                                                                             /* if (carry was set in addwf)
                                                                                                                                                          /* w = high byte of jmptbl addr
                                                                                                                                                                                                                           /* offset += low byte of jmptbl
                                                                                                                                                                               carry set if crossing page bounds
                                                                                             w += 1
                                                                                                                                                                                                                              addr
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            All
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  The
```

```
// equivalent to shift_left(&dstByte, 1, srcBit)
#define SHIFT_BIT_LEFT(dstByte, srcBit)
                                                                                                                                                                                                                                                                                                                                                                                                                                              #define ADVANCE_TMR0 (delta) TMR0 += ((delta)+2)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       jmptbl:
                                                                                                                                                                                   ::
                                                                                                                                                                                                                                                                                                                                 #define RETARD_TMR0(delta) TMR0 -= ((delta)-2)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          #define AWAIT_TMR0() while (!INTCON.TOIF)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      #define UPDATE_TMR0(tics) TMR0 += (256+2-(tics)); INTCON.TOIF=0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // Set TMR0 to roll over after a given number of tics.
// +2 term accounts for a two cycle inhbit when TMR0 is
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  #define SHORT_DISPATCH(offset)
                                                                                                                                                                                                                                                                                                                                                                          // make TMRO roll over delta tics later than scheduled
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          #define SET_TMR0(tics) TMR0 = (256+2-(tics)); INTCON.T0IF=0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          // once every instruction cycle.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           jmptbl:
                                                                                                        // shift srcBit into the LSB of dstByte
                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // make TMR0 roll over delta tics sooner than scheduled
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    // to SET_TMR0() or UPDATE_TMR0().
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     // to prevent accumulating timing errors.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // After an initial call to SET_TMRO(), you can use UPDATE_TMRO()
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  // Set TMR0 to roll over tics counts AFTER the previous roll over.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // Working with Timer 0 (aka RTCC)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             movwf PCLATH movf offset, w addwf PCL, f
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      // must be inside #asm context
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             // Shorter DISPATCH(), but valid iff table falls within current page
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         movphw jmptbl
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 Bug catching version. It takes a few extra precious cycles, but jumps to damn() with the caller's PC if INTCON.TOIF was set when AWAIT_TWR0() was first called.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          void damn() { gLoss++; }
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      Busy wait for the Timer 0 Interrupt Flag (T0IF). Assumes TMR0 has been set and that T0IF has been cleared by means of a previous call
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 +2 term accounts for a two cycle inhbit when TMR0 is set
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    Primarily intended for critical timing loops, these macros
                                                                                                                                                                                      Favorite time savers
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   int gLoss;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              #define AWAIT_TMR0() if (INTCON.TOIF) damn(); while (!INTCON.TOIF)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  assume that the TMR0 prescaler is set to "DIV_1" and counts
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           (doesn't increment PCLATH).
                                                                                                                                                                                                                        STATUS.C = srcBit;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              Takes 7 cycles (including goto ...)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             /* pcl += offset
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    ////
```

```
{}

// shift srcbit into the MSB of dstByte

// equivalent to shift right(&dstByte, 1, srcBit)

#define SHIFT BIT RIGHT(dstByte, srcBit)

STATUS.C = srcBit;
                                                                                                                                                                                                                                                   movlw arg
#endasm
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 #endasm
{}
#endif
#list
                                    #endasm
func()
                                                                                                             #endasm
func()
                                                                                                                                                                                                                                                                                                                                         #asm
                                                                                                                                                                                                                                                                                                                                                                                                   // direct access to W register, useful for passing single
// args to functions. eg:
   void wputc() {
      int ch;
      W_RECV(ch)
      ...
}
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     #asm
                                                                           #asm
                                                                                                                                                    #asm
                                                                                                                                                                                                                #asm
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               // sing W for passing arguments
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             #endasm
                                                                                  #define W_CALL_LIT(func, arg)
                                                                                                                                                             #define W_CALL(func, arg)
                                                                                                                                                                                       #endasm
                                                                                                                                                                                                                        #define W_RECV(arg)
                                                                                                                                                                                                                                                                                      #define W_PASSL(arg)
                                                                                                                                                                                                                                                                                                                 #endasm
                                                                                                                                                                                                                                                                                                                                                   #define W_PASS(arg)
                                                                                                                                                                                                movwf arg
                                                                                                                                                                                                                                                                                                                          movf arg, w
                                                            movlw arg
                                                                                                                                     movf arg,w
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         RLF dstByte, F
                                                                                                                                                                                                                                                                                                                                                                           W_CALL_LIT(wputc, 'a');
```