2 Description

Off-Grid Networking: Challenges and Opportunities

By way of background, consider the following networking challenges, all of which have been addressed by disparate MIT research efforts in the last six years:

1. How can we record and relay the weather on Mount Everest for a year [5]?

2. How can we put an ultramini camera with vital sign sensors onto a jaguar in the Belizean jungle, or a snow leopard in the Tibetan Himalaya, and receive live video?

3. How can we monitor the kinematics of cross-country skiers to analyze the most efficient skis, waxes and strides [2]?

4. How can we sense the health of a fragile coral reef ecosystem?

5. How can we put remote rural schools and clinics on line [4]?

6. How can we monitor the life of rare plants on a Hawaiian volcano [10]?

Each of these problems is soluble to some degree. But from the perspective of significantly improving the digital sensor and networked infrastructure, the problem is not whether or not they can be solved with a "patch." The problem is: what are the most effective, efficient and scalable solutions?

In the above list, some of the problems have unusual constraints; some exposed fundamental networking concepts; and all required considerable ingenuity, as they are all off-grid (power/com). Problems 1, 4 and 6 (mountains, reefs, plants) fall under the category of sensor networks for environmental monitoring [3]. The main challenge is to build probes that can run for months or years unattended and report data, reliably, into some known network (ie, web) location. For example, we built a weather probe for use on Mount Everest: a custom solution using the ARGOS satellite network for transmission, it supplied a dozen or more weather samples per day for nearly a year. While it is tempting to think of this sort of capability as akin to a "web cam," waiting to be sprinkled everywhere from golf courses to Mars, there is by no means a "plug and play" protocol for doing this. Most teams wind up cobbling together their own system solutions. As a consequence, this sort of infrastructure has not grown in abundance. In the case of coral reefs, a challenging variety of marine sensor networks are needed, with both underwater elements and surface relay nodes. And in the case of plant monitors, what we devised proved to be one of the very first self-organizing "mesh" networks: a simple array of sensors that were sprinkled in an environment and constituted their own "bucket brigade" to efficiently form a network [9,10]. This was a good example of an off-grid problem driving a generally applicable and interesting new form of networking. Although homes and buildings can now be networked almost effortlessly with 802.11, problems of networking a field environment generally remain a very real challenge. It is critical to do this well if we are to obtain a more accurate sense of the "pulse" of earth's ecosystems.

Problems 2 and 3 involve putting network elements on animals (including people), where nimbleness, mobilitiy, kinematic sensing, and physiological sensing pose the main challenges. For instance, our colleagues at National Geographic have had a long history in inventing animal-borne cameras [6-8]. These systems generally record on video cassettes (there is no network *per se*), so a big animal is needed to carry them. What is desired are video transmitters (the smaller the better), and to expand the information channels in order to transmit vital physiological information. In the case of predatory mammals, like jaguars, or roving ones, like whales, a significant territory needs to be covered with relay nodes. Such a system, if it worked well, would have many applications: micro air vehicles, for example.

Problem 5 is perhaps the most straightforward, but with the most palpable impact. Most of the world's schools have little or no connection: no phone, internet, and often no power. There are a number of efforts underway to bridge the so-called digital divide [4], and the benefits of doing so are well-known. Rural schools, when they are networked, can become a thriving community nexus, and in some cases the only link to the outside world. What is not so widely valued yet is that, with a rural school as a hub, nearby systems of many sorts (including ecological or animal monitoring systems) can not only share the infrastructure, but can benefit from sustained attention by the school. There is a technical aspect to this, in that, again, one needs the most readily deployable system (perhaps a mix including solar power, satellite/local wireless, and computers). Again, the best recipe for doing this is not well defined.

As a final observation, problems like those above have generally been dealt with in a piecemeal manner, both institutionally and technically. For instance, geologists need to do particular kinds of GPS surveys on mountains. Climatologists want weather probes. Foreign aid workers struggle to put schools on line in war-torn areas. Television producers want video cameras on penguins. Because of this, the resulting systems are balkanized and not synergistic. Perhaps more important, this pattern of work has not evolved significant new infrastructures. For example, most current digital infrastructure invention still happens in conventional laboratories with "indoor" thinking in mind. There are few incentives to stimulate computer science teams to tackle "outdoor" problems. The infrastructure might be enriched significantly by exploring advanced applications and inventions off the beaten path.

Work Plan

Our main goal for this grant is to scout what is most needed for off-grid networking challenges and develop a roadmap to produce it. "Scouting" means identifying critical technologies and important experimental sites for both a small pilot test under this grant, and development of a larger effort.

Because we have been intensively engaged in developing systems for the past several years, we plan to use a portion of this grant to understand what new sensor network technologies are emerging that might have application, and what holes need to be filled. For example, our seminal work on plant monitoring systems in Hawaii led to Ember, a startup company producing self-organizing radio networks. The first of those commercial components are now ripening for field deployment., and there are other commercial or quasi-commercial solutions emerging. We will investigate deployment possibilities, along with other "state of the shelf" emergent technologies. Where possible, we will gather technology samples to test.

It is clear that island ecologies offer a very challenging mix of problems, but we have only had a chance to scratch the surface. Colleagues in MIT's Earth Sciences program have done early work in Honduras, and now need to deploy much more substantial reef monitoring systems. Reefs are among the most biologically diverse ecosystems on earth; they are dying at a startling rate; and there is not a single reef system which has been effectively networked with sensors to obtain accurate ecological records. Our partners at the University of Hawaii would like to do more work on plant ecology, and a focused deployment of next-generation monitoring nodes is possible. A third example is Rongelap Atoll, where significant repatriation efforts have been underway, part of a resettlement process after military testing of nuclear devices during the second world war severely disrupted life there. In islands, the mix of marine-based and land-based systems, and the presence of sharply delineated endemic species, along with unusual community pressures, make for promising test sites. We will identify one, perhaps implement a small scale pilot project, and develop a larger plan.

A second category is crisis areas where ecological and human issues are in dire need. We have been asked, variously, to investigate the mountain gorillas in the Virunga rainforest of central Africa; to put video collars on snow leopards in Tibet; to participate in refugee camp management; and to work with education development in Afghanistan and Baghdad. In these cases, both human and ecological conditions are truly disastrous. For instance, the mountain gorillas, which number about 600, live in a habitat at the interstices of Rwanda, Uganda and Zaire. Overpopulation and genocidal war have ravaged the area, and poachers continue to slaughter gorillas. With projects such as these, there is a risk that the disastrous regional conditions and political unrest may make it infeasible to get new infrastructure to take root. On the other hand, only a sufficiently rugged, robust and decentralized network could survive in such an area. Again, we will scout these and other related research sites to determine which would be appropriate to advance work on digital infrastructure.

The goal of this surveying phase is to find the best new mix of technologies and site challenges to develop a more robust suite of off-grid networking solutions.

Timetable and Results

We will do this work in the coming 9-12 month period. Results will include assessment of one or more possible field sites and partnerships for addressing them, possibly one or two small pilot tests, and a significant new plan for advancing field sciences, and cyberinfrastructure in the field, at MIT.