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Underwater Sensor Networks :Architecture, Research Challenges and Potential Applications

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ABSTRACT

This paper explores architecture, research challenges and potential applications for underwater sensor networks. Sensor networks have the promise of revolutionizing many areas of science, industry, and government with their ability to bring computation and sensing into the physical world. This report summarizes our research directions in underwater sensor networks. We highlight potential applications to off-shore oilfields for seismic monitoring, equipment monitoring, and underwater robotics. We identify research directions in short- range acoustic communications, MAC, time synchronization, and localization protocols for high-latency acoustic networks, long-duration network sleeping, and application-level data scheduling.

***Keywords* - acoustic communications, acoustic networks, seismic monitoring, time synchronization, underwater sensor networks,**

I. INTRODUCTION

Sensor networks have the promise of revolutionizing many areas of science, industry, and government. The ability to have small devices physically distributed near the objects being sensed brings new opportunities to observe and act on the world, for example with micro-habitat monitoring [6], [17], structural monitoring [5], and industrial applications [7]. While sensor-net systems are beginning to be fielded in applications today on the ground, underwater operations remain quite limited by comparison. Remotely controlled submersibles are often employed, but as large, active and managed devices, their deployment is inherently temporary. Some wide-area data collection efforts have been undertaken, but at quite coarse granularity (hundreds of sensors to cover the globe) [3]. Even when regional approaches are considered, they are often wired and very expensive [12]. The key benefits of terrestrial sensor networks stem from wireless operation, self-configuration, and maximizing the utility of any energy consumed. They emphasize low cost nodes (around US$100), dense deployments (at most a few 100m apart), short-range, multihop communication; by comparison, underwater acoustic communication today are typically expensive (US$10k or more), sparsely deployed (a few nodes, placed kilometers apart), typically communicating directly to a “base station” over long ranges rather than with each other. We are currently exploring how to extend the benefits of terrestrial sensor networks to *underwater sensor networks (UWSNs)with acoustic communications*. Underwater sensor networks have many potential applications. Here we briefly consider seismic imaging of undersea oilfields as a representative application. Today, most seismic imaging tasks for offshore oilfields are carried out by a ship that tows a large array of hydrophones on the surface. The cost of such technology is very high, and the seismic survey can only be carried out rarely, for example, once every 2–3 years. In comparison, sensor network nodes have very low cost, and can be permanently deployed on the sea floor. Such a system enables frequent seismic imaging of reservoir (perhaps every few months), and helps to improve resource recovery and oil productivity. The following Fig.-1 shows the schematic diagram of UWSNs.

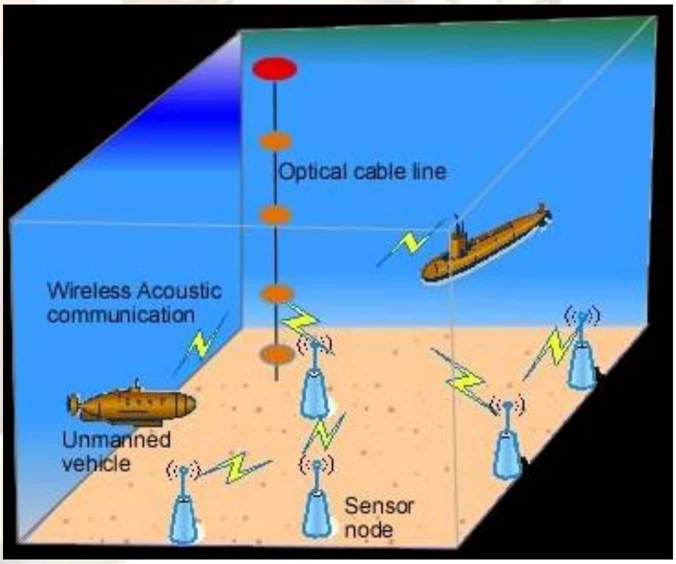

Fig.1: Underwater sensor networks

To realize underwater applications, we can borrow many design principles and tools from ongoing, ground-based sensor net research. However, some of the challenges are fundamentally different. First, radio is not suitable for underwater usage because of extremely limited propagation (current mote radios transmit 50–100cm). While acoustic telemetry is a promising form of underwater communication, off-the-shelf acoustic modems are not suitable for underwater sensor-nets with hundreds of nodes: their power draws, ranges, and price points are all designed for sparse, long-range, expensive systems rather than small, dense, and cheap sensor-nets. Second, the shift from RF to acoustics changes the physics of communication from the speed of light ($3X10^8$m/s) to the speed of sound (around $1.5X10^3$m/s) a difference of five orders of magnitude. While propagation delay is negligible for short-range RF, it is a central fact of underwater wireless. This has profound implications on localization and time synchronization. Finally, energy conservation of underwater sensor-nets will be different than on-ground because the sensors will be larger, and because some important applications require large amounts of data, but very infrequently (once per week or less). We are therefore investigating three areas: hardware, acoustic communication with sensor nodes, protocols, underwater network self-configuration, MAC protocol design, time synchronization, and localization and mostly-off operation, energy-aware data caching and forwarding. We believe that low-cost, energy conserving acoustic modems are possible, and that our focus on short-range communication can avoid many of the challenges of long-range transfer. Development of multi-access, delay-tolerant protocols are essential to accomplish dense networks. Low-duty cycle operation and integration with the application can cope with limited bandwidth and high latency.

II. SYSTEM ARCHITECTURE

Before describing specific applications, we briefly review the general architecture we envision for an underwater sensor network. Figure2 shows a diagram of our current tentative design. We anticipate a tiered deployment, where some nodes have greater resources.

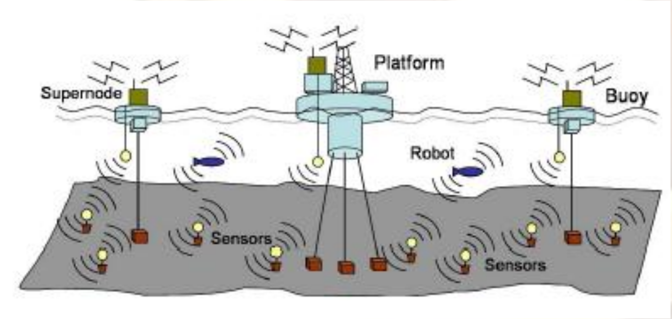

Fig. 2: Underwater network deployment.

In Fig. 2, we see four different types of nodes in the system. At the lowest layer, the large number of sensor nodes are deployed on the sea floor (shown as small yellow circles). They collect data through attached sensors (e.g., seismic) and communicate with other nodes through short-range acoustic modems. They operate on batteries, and to operate for long periods they spend most of their life asleep. Several deployment strategies of these nodes are possible; here we show them anchored to the sea floor. (They could also be buried for protection.) Tethers ensure that nodes are positioned roughly where expected and allow optimization of placement for good sensor and communications coverage. Node movement is still possible due to anchor drift or disturbance from external effects. We expect nodes to be able to determine their locations through distributed localization algorithms. At the top layer are one or more control nodes with connections to the Internet. The node shown on the platform in Figure 2 is this kind of node. These control nodes may be positioned on an off-shore platform with power, or they may be on-shore; we expect these nodes to have a large storage capacity to buffer data, and access to ample electrical power. Control nodes will communicate with sensor nodes directly, by connecting to an underwater acoustic modem with wires. In large networks, a third type of nodes, called super-nodes, can be deployed. Supernodes have access to high speed networks, and can relay data to the base station very efficiently. We are considering two possible implementations: first involves attaching regular nodes to tethered buoys that are equipped with high-speed radio communications to the base station, as shown in the figure 2. An alternative implementation would place these nodes on the sea floor and connect them to the base station with fiber optic cables. Supernodes allow a much richer network connectivity, creating multiple data collection points for the underwater acoustic network. Finally, although robotic submersibles are not the focus of the current work, we see them interacting with our system via acoustic communications. In the figure, dark blue “fishes” represent multiple robots. CPU capability at a node varies greatly in current sensor networks, from 8-bit embedded processors, such as Berkeley Motes to 32-bit embedded processors about as powerful as typical PDAs, such as Intel Stargates to 32-bit or 64-bit laptop computers. We see Stargate-class computers as most appropriate for underwater sensor networks for several reasons. Their memory capacities (64MB RAM, 32MB flash storage) and computing power (a 400MHz XScale processor) is sufficient to store and process a significant amount of data temporarily, while their cost is moderate (currently US$600/each). Although Moteclass computers are attractive in cost and energy performance, their very limited memory (4–8kB of RAM and 64–1024MB of flash storage) is a poor match for the requirements of underwater applications. In a harsh underwater environment, we must anticipate that some nodes will be lost over time. Possible risks include fishing trawlers, underwater life, or failure of waterproofing. We therefore expect basic deployments to include some redundancy, so that loss of an individual node will not have wider effects. In addition, we expect that we will be able to recover from multiple failures, either with mobile nodes, or with deployment of replacements. Operating on battery power, sensor nodes must carefully monitor their energy consumption. It is essential that all components of the system operate at as low a duty cycle as possible. In addition, we expect to coordinate with the application to entirely shut off the node for very long periods of time, up to days or months. We also expect to build on techniques for long-duration sleep. Communications between nodes is an important focus of our work, because we see a large gap between our target deployment and currently available commercial, long-range, high power, point-to-point, acoustic communications. The networking protocols that allow underwater nodes to self-configure and coordinate with each other, such as time synchronization, localization, MAC and routing. Finally, we have some basic assumptions about the applications that match these design. First, application benefit from local processing and temporary data storage. Storage can be used to buffer data to manage low-speed communications, "time-shifting" data collection from retrieval. In some cases, nodes benefit from pair wise communications and computation. Finally, in most sensing applications, we expect the data to be eventually relayed to the user through the Internet or a dedicated network.

III. RESEARCH CHALLENGES IN UWSNs

Major challenges encountered in the design of underwater acoustic networks are as follows [10] [11].

1) It is necessary to develop less expensive, robust ''nano-sensors'', e.g., sensors based on nanotechnology, which involves development of materials and systems at the atomic, molecular, or macromolecular levels in the dimension range of approximately 1–500 nm.
2) It is necessary to devise periodical cleaning mechanisms against corrosion and fouling, which may impact the lifetime of underwater devices.
3) There is a need for robust, stable sensors on a high range of temperatures since sensor drift of underwater devices may be a concern. To this end, protocols for in situ calibration of sensors to improve accuracy and precision of sampled data must be developed.
4) There is a need for new integrated sensors for synoptic sampling of physical, chemical, and biological parameters to improve the understanding of processes in marine systems.
5) The available bandwidth is severely limited.
6) The underwater channel is impaired because of multi-path and fading.
7) Propagation delay in underwater is five orders of magnitude higher than in Radio Frequency (RF) terrestrial channels, and variable.
8) High bit error rates and temporary losses of connectivity (shadow zones) can be experienced.
9) Underwater sensors are characterized by high cost because of extra protective sheaths needed for sensors and also relatively small number of suppliers (i.e., not much economy of scale) are available.
10) Battery power is limited and usually batteries cannot be recharged as solar energy cannot be exploited.
11) Underwater sensors are more prone to failures because of fouling and corrosion.

IV. POTENTIAL APPLICATIONS OF UWSNs

The application of wireless sensor networks to the underwater domain has huge potential for monitoring the health of river and marine environments [4]. Monitoring these environments is difficult and costly for humans: divers are regulated in the hours and depths at which they can work, and require a boat on the surface that is costly to operate and subject to weather conditions.

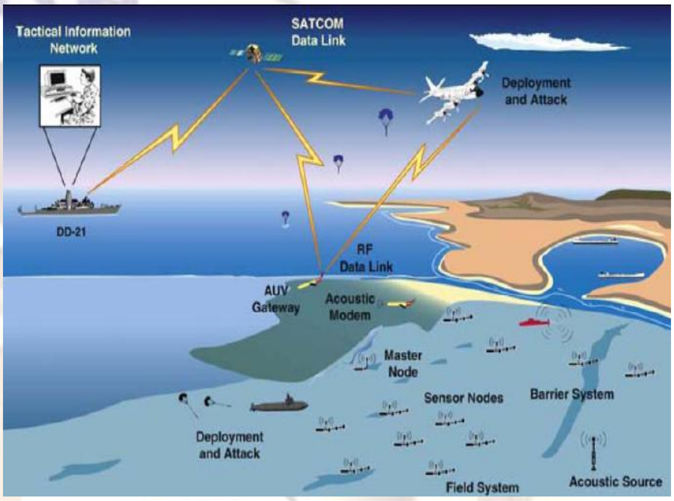

Fig3: Anti-submarine warfare

The above Fig. 3 shows Anti-submarine warfare is a branch of naval warfare that uses surface warships, aircraft, or other submarines to find, track and deter, damage or destroy enemy submarines. A sensor network deployed underwater could monitor physical variables such as water temperature and pressure as well as variables such as conductivity, turbidity and certain pollutants. The network could track plumes of silt due to dredging operations or pollutants owing in from land, and it could monitor and model the behavior of underwater ecosystems. Imaging sensors could be used to measure visible change in the environment or count, and perhaps even classify species and also useful for disaster prevention. The applications of underwater sensor networks are classified as follows .

1) *Ocean sampling* Networks of sensors and AUVs, such as the Odyssey-class AUVs[2] can perform synoptic, cooperative adaptive sampling of the 3D coastal ocean environment. Experiments such as the Monterey Bay field experiment demonstrated the advantages of bringing together sophisticated new robotic vehicles with advanced ocean models to improve the ability to observe and predict the characteristics of the oceanic environment.

2) *Environmental monitoring* UW-ASNs can perform pollution monitoring (chemical, biological and nuclear). For example, it may be possible to detail the chemical slurry of antibiotics, estrogen-type hormones and insecticides to monitor streams, rivers, lakes and ocean bays (water quality in situ analysis). Monitoring of ocean currents and winds, improved weather forecast, detecting climate change, under-standing and predicting the effect of human activities on marine ecosystems, biological monitoring such as tracking of fishes or micro-organisms, are other possible applications. For example, in the design and construction of a simple underwater sensor network is described to detect extreme temperature gradients, which are considered to be a breeding ground for certain marine micro-organisms.
3) *Undersea explorations* Underwater sensor networks can help detecting underwater oilfields or reservoirs, determine routes for laying undersea cables, and assist in exploration for valuable minerals.
4) *Disaster prevention* Sensor networks that measure seismic activity from remote locations can provide tsunami warnings to coastal areas, or study the effects of submarine earthquakes (seaquakes).
5) *Assisted navigation* Sensors can be used to identify hazards on the seabed, locate dangerous rocks or shoals in shallow waters, mooring positions, submerged wrecks, and to perform bathymetry profiling.
6) *Distributed tactical surveillance* autonomous underwater vehicles(AUV) and fixed underwater sensors can collaboratively monitor areas for surveillance, reconnaissance, targeting and intrusion detection systems. For example, a 3D underwater sensor network is designed for a tactical surveillance system that is able to detect and classify submarines, small delivery vehicles (SDVs) and divers based on the sensed data from mechanical, radiation, magnetic and acoustic micro sensors. With respect to traditional radar/sonar systems, underwater sensor networks can reach a higher accuracy, and enable detection and classification of low signature targets by also combining measures from different types of sensors.
7) *Mine reconnaissance* simultaneous operation of multiple AUVs with acoustic and optical sensors can be used to perform rapid environmental assessment and detect mine-like objects.
8) *Flocks of Underwater Robots* a very different application is supporting groups of underwater autonomous robots. Applications include coordinating adaptive sensing of chemical leaks or biological phenomena (for example, oil leaks or phytoplankton concentrations), and also equipment monitoring applications.

V. RELATED WORK

These research directions build on related work from several communities: the oil industry as a potential user of underwater sensor networks, oceanographic researchers who build underwater sensing and communication systems, and the wireless sensor network community. While summarizing existing work, we will also point out what is new in our proposed research.

Seismic imaging in oil industry Three-dimensional (3-D) seismic imaging and monitoring is an important technology for oil exploration and reservoir management in the oil industry. Advanced reservoir management with 3-D seismic (sometimes 4-D with time series) can significantly improve resource recovery and oil productivity. Today, most seismic imaging tasks for offshore oilfields are carried out by a ship that tows a large array of hydrophones on the surface.A compressed-air gun generates a shock wave in the water. The wave travels down the sea floor and is reflected by different layers of the rock. The seismic signal is eventually received by each hydrophone on surface, and the data are processed coherently to form an image. Due to the high cost of such seismic imaging, it is only performed rarely, for example, once a year. An alternative way that has been used for underwater seismic is to deploy sensors underwater, which are connected by cables. The approach has the advantage of frequent data collection. However, it is very costly to lay cables underwater for a large area. We propose a different approach for underwater seismic using underwater wireless sensor networks. The sensor network consists of large numbers of smart sensors, and each of them has an embedded processor, sensors (seismic and others), storage memory, and acoustic communication devices. These nodes are battery powered, and are deployed in an ad hoc way without careful planning. Once deployed, the nodes will organize themselves into a multi-hop communication network, and gradually move sensing data back to users. Our approach is new for undersea seismic imaging, and it has several advantages over existing ones. First, it is cost effective. These smart sensors are very cheap, so a large number of them can be deployed to cover a large monitoring area with enough density. Second, it is easy to deploy. It does not require special planning or extensive cable connections. Finally, it enables frequent seismic survey once the network is deployed.

Oceanographic research is another related community , where researchers have developed underwater sensing and communication systems. The following fig. 4 shows the oceanography.

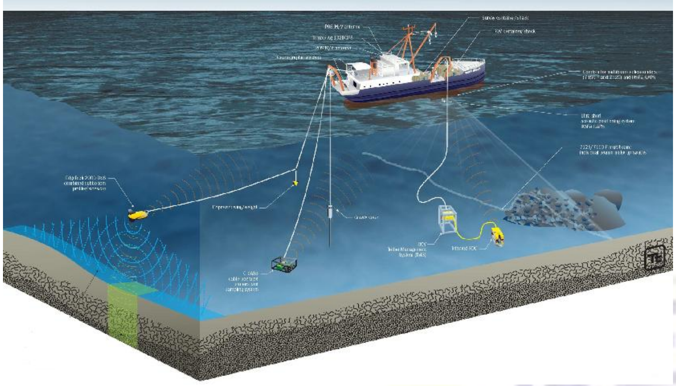

Fig. 4: Oceanography

An example is the Ocean Seismic Network program. It developed seismic observatories in the deep ocean, as part of the Global Seismic Network (GSN). GSN has 128 observatories “uniformly” distributed on continents, islands or in the ocean, with a separation distance of 2000km. Its goal is to monitor a huge area on earth. In contrast, our sensor network covers a much smaller area, and nodes are densely deployed in an ad hoc fashion. In GSN, there is no direct communications between the sensing stations. They all directly send their data back to a central place. In sensor networks, the nodes will configure themselves to form a multi-hop communication network. In summary, the GSN is still the traditional way to do seismic imaging, but it covers a huge area including nodes in the ocean. Underwater acoustic communication is another related
area. The basic communication principles have been examined with acoustic channels in [8, 9]. Their major focus is the transmission range, bandwidth utilization and reliability with multi-path propagations. There are also experimental and commercial off-the-shelf acoustic modems available today, such as [3, 2, 16]. However, these modems are designed for long range communications (1.90km), and have weights of over 4kg. In our proposed hardware design, we will focus on short range, low-power modules in a small package. This capability is an enabling factor for long-lived sensor networks. Networking protocols with acoustic communications are also studied in the literature. In [4], the authors reviewed MAC and routing protocols for wireless ad hoc networks. They also analyzed energy consumption with transmission range in acoustic transmissions, and pointed out that shortrange, multi-hop relaying was the key for energy conservation. In [13], the authors proposed a clustering protocol with combined TDMA and CDMA for a group of autonomous underwater vehicles. These researches are based on an ad hoc networking model with small to moderate number of nodes. In contrast, our sensor network model consists of large numbers of nodes (hundreds to thousands), and our application has different requirements. The challenges we identified in this paper was not addressed by the existing work.

Wireless sensor networks Using wireless sensor networks for seismic imaging is not a new idea in the sensor network community. But all existing work are based on radio communications among sensors. Our goal is to extend sensor networking technology to underwater applications with acoustic communications. So far, virtually all platforms developed for wireless sensor networks use radio communications. One of most widely used platforms is the UC Berkeley mote[14], which is based on a 8-bit microcontroller, and a short-range, low power radio. 32-bit platforms are normally embedded PCs, such as PC/104s and Stargates [15]. These big nodes do not have build-in radios, but can be connected with either motes or IEEE 802.11 cards. Although the radio propagation in water is very bad, the motes are still used by researchers in marine microorganism monitoring applications[1]. We plan to extend sensor network platforms with a low-power, short range acoustic communication device, so that large-scale underwater experiments and applications become possible. There are several networking protocols and algorithms directly related to our proposed research.

VI. CONCLUSION

In this paper, we presented an overview of the state of the art in underwater acoustic sensor network. We described the challenges posed by the peculiarities of the underwater channel with particular reference to monitoring applications for the ocean environment. The ultimate objective of this paper is to encourage research efforts to lay down fundamental basis for the development of new advanced communication techniques for efficient underwater communication and networking for enhanced ocean monitoring and exploration applications. Underwater Acoustic Sensor Networks will consist of sensors and vehicles deployed underwater and networked via acoustic links to perform collaborative monitoring tasks. In this paper, we have presented the basic conceptual architecture of underwater acoustic sensor network. We have discussed the challenges posed by the underwater channel, and applications of UWSNs. By the literature survey, we may conclude that research on the underwater sensor network is still in the developing stage.

REFERENCES

[1] Bin Zhang, Gaurav S. Sukhatme, and Aristides A.Requicha. Adaptive sampling for marine microorganism monitoring. In IEEE/RSJ International Conference on Intelligent Robots and Systems, 2004.

[2] R. A. Stephen. Ocean seismic network seafloor observatories. Oceanus, 41(1):33–37, Spring 1998.

[3] Joseph A. Rice. Undersea networked acoustic communication and navigation for autonomous minecountermeasure systems. In Proceedings of the 5th International Symposium on Technology and the Mine Problem, Monterey, CA, April 2002.

[4] Ethem M. Sozer, Milica Stojanovic, and John G. Proakis. Underwater acoustic networks. IEEE Journal of Oceanic Engineering, 25(1):72.83, January 2000.
[5] D. Whang, N. Xu, S. Rangwala, K. Chintalapudi, R. Govindan, and J. Wallace. Development of an embedded sensing system for structural health monitoring. In Proceedings of the International Workshop on Smart Materials and Structures Technology, Jan. 2004.
[6] A. Cerpa, J. Elson, D. Estrin, L. Girod, M. Hamilton, and J. Zhao. Habitat monitoring: Application driver for wireless communications technology. In Proceedings of the ACM SIGCOMM Workshop on Data Communications in Latin America and the Caribbean, Apr. 2001.
[7] N. Ramanathan, M. Yarvis, J. Chhabra, N. Kushalnagar, L. Krishnamurthy, and D. Estrin. A stream-oriented power management protocol for low duty cycle sensor network applications. In Proceedings of the IEEE Workshop on Embedded Networked Sensors, Sydney, Australia, May 2005. [8] M. Stojanovic. Recent advances in high-speed underwater acoustic communications. IEEE Journal of Oceanic Engineering, 21:125.136, April 1996.
[9] M. Stojanovic, J. G. Proakis, J. A. Rice, and M. D. Green. Spread-spectrum methods for underwater acoustic. In Proceedings of the IEEE OCEANS'98 Conference, volume 2, pages 650.654, Nice France, September 1998.
[10] J.H. Cui, J. Kong, M. Gerla, and S. Zhou, Challenges: Building scalable mobile underwater wireless sensor networks for aquatic applications, IEEE Network, Special Issue on Wireless Sensor Networking, pp. 12-18, 2006. [11] I. F. Akyildiz, D. Pompili, and T. Melodia, Underwater acoustic sensor networks: Research challenges, Ad Hoc Networks, pp. 257–279, 2005.
[12] J. R. Delaney and A. D. Chave. Neptune: A fiber-optic 'telescope' to inner space. Oceanus, 42(1):10–11, spring 2000.
[13] Benthos, Inc., http://www.benthos.com/pdf/ Modems/ModemBrochure.pdf. Fast And Reliable Access To Undersea Data.
[14] Crossbow Technologies, Inc., http://www.xbow.com/. Mica2 Data Sheet.
[15] Francisco Salva-Garau and Milica Stojanovic. Multicluster protocol for ad hoc mobile underwater acoustic networks. In Proceedings of the IEEE OCEANS'03 Conference, San Diego, CA, September 2003.
[16] LinkQuest, Inc., http://www.link-quest.com/html/uwm_hr.pdf. Underwater Acoustic Modems.
[17] A. Mainwaring, J. Polastre, R. Szewczyk, and D. Culler. Wireless sensor networks for habitat monitoring. In Proceedings of the ACM Workshop on Sensor Networks and Applications, Atlanta, Georgia, USA, Sept. 2002.