Underwater Sensor Networking

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Abstract

Underwater Sensor Networks are highly distributed self-organized systems. I highlight potential applications to off-shore oilfields for seismic monitoring, equipment monitoring, and underwater robotics. Its 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. In this survey paper, I provide a full view of the studies in this area.

Keywords: Application-Level Data Scheduling, Distributed Self-Organized Systems, Equipment Monitoring, Sensor Networking, Underwater Robotics.

I. INTRODUCTION

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. The ability to have small devices physically distributed near the objects being sensed brings new opportunities to observe and act on the world. While sensor-net systems are beginning to be fielded in applications today on the ground, *underwater* operations remain quite limited by comparison.

Underwater sensor networks have many potential applications, including seismic monitoring, equipment monitoring and leak detection, and support for swarms underwater robots. One major reason to choose this application is that underwater sensor network is able to provide significant economic benefits over traditional technology. Today, most seismic imaging tasks for offshore oilfields are carried out by a ship that tows a large array of hydrophones on the surface. To realize these applications, an underwater sensor network must provide many of the tools that have been developed for terrestrial sensor networks: wireless communication, low-power hardware, energy conserving network protocols, time synchronization and localization, and programming abstractions.

They are therefore investigating three areas: *hardware*, acoustic communication with sensor nodes; *protocols*, underwater-network network self-configuration, MAC protocol design, time synchronization, and ranging; and *mostly-off operation*, data caching and forwarding and energy-aware system design and ultra-low duty cycle operation. They 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 and involvement of the application can cope with limited bandwidth and high latency. They begin by reviewing their overall Architecture and the constraints placed on their work by several applications.

II. SYSTEM ARCHITECTURE

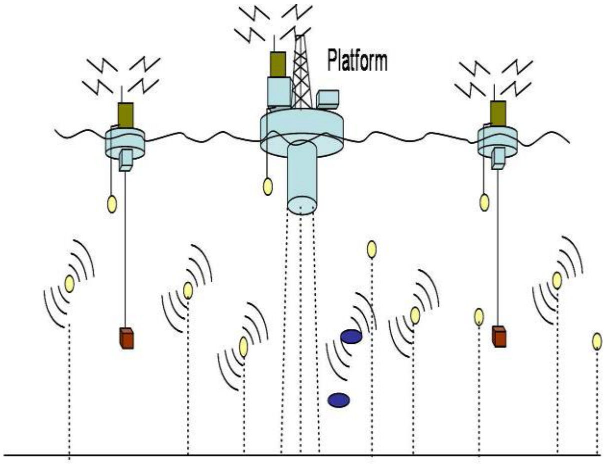

Fig. 1: One possible approach to node deployment

Before describing specific applications, I next briefly review the general architecture envision for an underwater sensor network. They begin by considering the rough capabilities of an individual underwater sensor node, how it interacts with its environment, other underwater nodes, and applications. Figure 1 shows a logical diagram of a potential system. We see four different types of nodes in the system. At the lowest layer is the large number of sensor nodes to be deployed on or near the sea floor (shown as small yellow circles in the figure). They have moderate price, computing power, and storage capacity. They collect data through their sensors and communicate with other nodes through short-range acoustic modems. They have batteries, but for long-term operation they spend most of their life asleep.

At the top layer are one or more control nodes with connections to the Internet, and possibly human operators. 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, via a relay node: a sensor node with underwater acoustic modems that is connected to the control node with a wired network. In large networks, a third type of nodes, called *super nodes*, have access to higher speed networks.

III. APPLICATIONS

They see their approaches as applicable to a number of applications, including seismic monitoring, equipment monitoring and leak detection, and support for swarms underwater robots. We review the different characteristics of each of these below.

A. Seismic monitoring

A promising application for underwater sensor networks is seismic monitoring for oil extraction from underwater fields. Frequent seismic monitoring is of importance in oil extraction; studies of variation in the reservoir over time are called .4-D seismic. and are useful for judging field performance and motivating intervention.

B. Equipment Monitoring and Control

Underwater equipment monitoring is a second example application. Ideally, underwater equipment will include monitoring support when it is deployed, possibly associated with tethered power and communications, thus our approaches are not necessary. However, *temporary* monitoring would benefit from low-power, wireless communication.

IV. HARDWARE FOR UNDERWATER ACOUSTIC COMMUNICATIONS

We have described why underwater *acoustic communications* is an important alternative to radio-frequency (RF) communications for these networks.

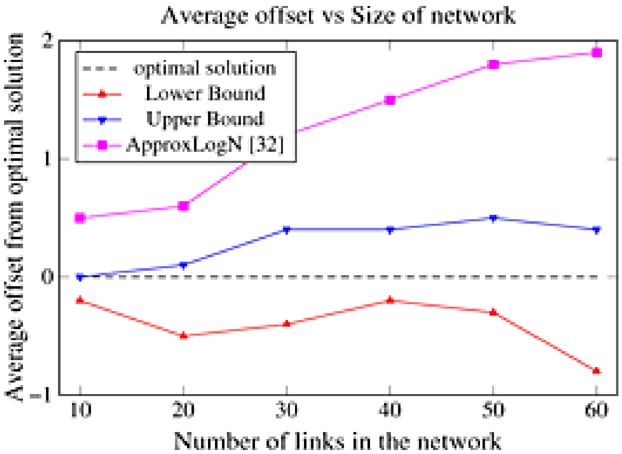

Fig. 2: Modified S-MAC schedules to accommodate large propagation delay.

Figure 2 shows the periodic listen and sleep schedule of a sensor node running S-MAC in low duty cycles.

A. Transmit Power

There is no fundamental limit to transmitter power, but it can have a major effect on the power budget for the system. For energy efficiency and to minimize interference with neighboring transmitters we wish to use the smallest possible transmitter power.

B. Data Rate

This is a tradeoff in the system design, based on available power, and channel bandwidth. Because acoustic communications are possible only over fairly limited bandwidths, we expect a fairly low data rate by comparison to most radios. We see a rate of currently 5kb/s and perhaps up to 20kb/s. Fortunately these rates are within an order of magnitude of RF-based sensor networks. In application such as robotic control, the ability to communicate *at all* (even at a low rate) is much more important than the ability to send very large amounts of data quickly. In addition, in Section 5.5 we describe how application-level techniques can be used to maximize the benefits of even limited communications rates.

C. Noise Level

Noise levels in the ocean have a critical effect on sonar performance, and have been studied extensively. We are interested in the frequency range between 200 Hz and 50 kHz (the *mid frequency band*). In this frequency range the dominant noise source is wind acting on the sea surface. Knudsen has shown a correlation between ambient noise and wind force or sea state. Ambient noise increases about 5dB as the wind strength doubles. Peak wind noise occurs around 500 Hz, and then decreases about -6dB per octave. At a frequency of 10,000 Hz the ambient noise spectral density is expected to range between 28dB/Hz and 50dB/Hz relative to 1 micro Pascal. This suggests the need for wide range control of transmitter power.

D. Signal Attenuation

Signal attenuation is due to a variety of factors. Both radio waves and acoustic waves experience 1=*R*2 attenuation due to spherical spreading. There are also absorptive losses caused by the transmission media. For RF transmission, atmospheric losses are quite small. Absorptive losses in underwater acoustics are significant and very frequency dependent. At 12.5 kHz absorption it is 1 dB/km or less. At 70 kHz it can exceed 20dB/km. This places a practical upper limit on our carrier frequency at about 100kHz.

E. Proposed Acoustic Communications Design

Many of these forms of loss are unique to acoustic communications at *longer* distances. In particular, multipath reflections, temperature variation, and surface scattering are all exaggerated by distance. Inspired by the benefits of short range RF communication in sensor networks, we seek to exploit *short-range underwater acoustics* where our only significant losses are spreading and absorption. We are developing a multi-hop acoustic network targeting communication distances of 50-500 meters and communication rates of around 5kb/s.

V. PROTOCOLS FOR HIGH-LATENCY NETWORKS

Acoustic communication puts new constraints *networks* of underwater sensor nodes for several reasons. First, the large propagation delay may break or significantly degrade the performance of many current protocols. The speed of sound in sea water is roughly 1:5_103m/s. The propagation delay for two nodes at 100m distance is therefore about 67ms. Second, the bandwidth of an acoustic channel is much lower than that of a radio. Efficient bandwidth utilization becomes an important issue. We next examine several research directions to provide this support for the underwater sensor networks.

A. Latency-Tolerant MAC Protocols

MAC protocols suitable for sensor networks can be broadly classified into two categories: scheduled protocols and contention-based protocols. TDMA is a typical example of the scheduled protocols. It has good energy efficiency, but it requires strict time synchronization and is not flexible to changes in the number of nodes. Contention based protocols are normally based on CSMA, and some collision avoidance mechanisms, such as RTS/CTS exchange, are also commonly used.

B. Time Synchronization

Time synchronization provides fundamental support for many protocols and applications. Without GPS, time synchronization algorithms have to be completely distributed over peering nodes. Several algorithms have been developed for radio-based sensor networks, achieving the accuracy of tens of microseconds [19, 22]. However, they assume nearly instantaneous wireless communication between sensor nodes, which is valid enough (0.33μs for nodes over 100m) for current RF-based networks.

VI. CONCLUSIONS

This paper has summarized our ongoing research in underwater sensor networks, including potential applications and research challenges.

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