Demo Abstract: Bringing Sensor Networks Underwater with Low-Power Acoustic Communications*

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Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Wireless communication; Distributed networks

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1. INTRODUCTION

Sensor networks are changing how data is collected in many applications on earth today. However, today's sensornets do not address the 71% of the earth's surface that is covered by water. Just as sensornets benefit environmental monitoring and industrial control on land, environmental monitoring in oceans and lakes, and control of underwater industrial processes can benefit from sensor networks [4, 2].

While underwater sensornets can exploit the same computation and storage approaches of terrestrial sensornets, radio networks are simply not viable underwater because water absorptions most radio frequencies. Acoustic modems are a viable alternative, but most commercial acoustic modems today target long-distance, point-to-point communication with high-power consumption and high costs. While matched for some vertical applications that are fielded today, these modems are the antithesis of a sensornet, which calls for short-range, low-power, many-to-many communications, and small, inexpensive platforms.

We are developing a new underwater acoustic modem targeted at the needs of sensor networks [7]. Our design targets low cost (∼\$100, plus hydrophones), short range (less than 500m), and relatively low bit rates (1kbaud). As with sensornet radios, we support transmit power control and exploit CPU capabilities to get the flexibility of software-level bit decoding. A unique feature of our modem is an ultra low power wake-up circuit (100μA at 5V), which can be activated by a short wake-up tone. We exploit wake-up tones by developing T-Lohi, an underwater media access protocol that is efficient in both energy and throughput [6].

We demonstrate both overall operation and to highlight the unique features of our modem. We show end-to-end data transmission (PC-to-PC, through motes operating as NICs, modems, and hydrophones in water). We show the energy conservation of wake-up tone triggered activation. Finally, we show how our our bit-synchronization algorithm handles clock drift and Doppler shifts during packet transmission by re-synchronize after repeated partial errors.

2. MODEM OVERVIEW

2.1 SNUSE Acoustic Modem

Our SNUSE modem is designed to capture the key aspects of RF-based sensornet platforms (such as Mica-2 and MicaZ motes with Chipcon CC1000 and 802.15.4 radios) in an underwater, acoustic environment [7]. We lay out our design goals above, focusing on low power and cost. In addition, it includes support to ease testing and development, such as optionally independent transducers for transmission and reception, and support for both in-air and underwater acoustic operation. Other acoustic modems currently exist, however these modems do not share the same goals of our low-power, low-cost, and short range communication [8, 1].

The basic modem design operates with FSK modulation over the 17–19kHz range. It is designed to operate at 1 kbaud, although we currently underclock it at 512 baud. We expect to operate at full speed in our next hardware revision, version 3 planned in late 2008.

The modem incorporates a custom wake up receiver, listening for wake-up tones at 18kHz. This wakeup receiver can trigger modem operation even when all other components are powered down; in this modem it draws only about 100μA at 5V. Our T-Lohi MAC protocol (described in Section 2.3) uses tones to provide energy-conserving signalling.

2.2 Physical-Layer Software Implementation

The hardware described above provides basic functions of transmitting and receiving raw bits and wakeup tones. To support packet-level communication, we implement other physical layer components in software on a Mica-2 mote that runs TinyOS [5, 3].

We divide the physical layer into two components. The lower level one controls the modem states, and performs start symbol detection, bit-level transmission and reception, transmit power control, and RSSI measurement. The higher level component provides a packet-level interface to MAC and other applications. It performs channel coding, CRC checking, and time stamping on each each packet.

We develop a robust bit-synchronization algorithm that addresses high noise typical of acoustic channels. For each incoming symbol, we take three samples and vote to determine a value. We automatically resynchronize to account for clock drift or Doppler shifts caused by moving nodes. Such effects can occur in acoustic communications due to the slow data rate and imperfect timing. Our experiments show that the bit re-sync algorithm can improve our packet reception rate from 40% to 100%.

Symbol re-sync does keeps track of consistent mismatches

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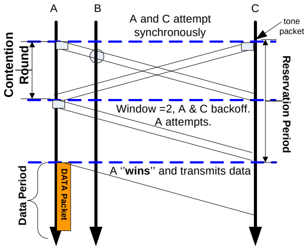

Figure 1: The Tone-Lohi protocol frame

in the first and the last samples for the last eight bits. By tracking the mismatch history, the algorithm learns whether the receiver's clock is running faster or slower than the transmitter's clock. Thus the receiver is able to adjust its clock properly to correct changes in synchronization. It greatly improves robustness of packet reception.

2.3 Planned Media-Access Layer

The primary objective of our underwater MAC protocol, T-Lohi [6], is to provide efficient channel utilization, stable throughput, and low energy consumption. T-Lohi makes data packet collisions unlikely by use of contention to reserve medium, thus avoiding loss of throughput and energy waste. T-Lohi also exploits our modem's low-power wake-up receiver by using wake-up tones to indicate contention, further reducing energy waste [7].

In T-Lohi MAC, nodes contend to reserve the channel to send data. Figure 1 shows an example of this process: nodes A and C have data to transmit but first send tones indicating contention in fixed length rounds. Detecting other tones provides a count of current contenders: A and C have a count of two and back-off to attempt uniformly in one of the next *two* rounds. If no other tone is detected in a given round (as A does in round two), collision free data transmission occurs in the subsequent round.

We are in the process of implementing T-Lohi on our hardware. In this demo we demonstrate low-power wake-up circuit at the core of T-Lohi.

3. DEMONSTRATION

We have operated our modem in several environments, including in-air testing with tweeters as actuators, water tests in the laboratory, and water tests in the Marina Del Rey harbor. For Sensys we will show our demonstration in a tub for ease of deployment. Our experimental setup can be seen in Figure 2. Our demonstration will have several components: data transmission, PHY demonstration, and wakeup demonstration.

For *data transmission*, users type in a message on the sender PC which passes the user data to a Mica-2 mote via a serial cable. The software on the mote arranges the text in to an appropriate packet format, and performs channel coding and CRC calculation. The mote derives the modem transmitter to send each bit out to the attached hydrophone.

On the receiver side, the packet gets picked up by the receiving hydrophone. The receiver-side modem does hardware detection and provides an analog bit pattern. The receiver's Mica-2 mote performs bit detection and synchronization as well as packet framing and decoding. After checking the CRC, it passes the packet to the PC to display the packet content.

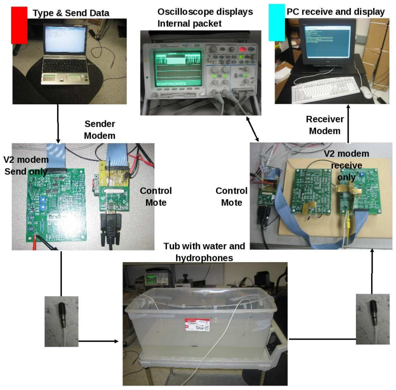

Figure 2: Hardware setup for demonstration of through-water data transmission.

We will demonstrate some *details of the physical-layer reception algorithm*, including oversampling, voting, and bit-resynchronization to handle clock drift. These signals will be extracted from the receive-side modem and displayed on an oscilloscope, with a description of the relevant algorithms on an accompanying poster.

To demonstrate our *low-power wake-up circuit* we use a modem board with wake-up capabilities. Currently our modem is in integration phase with separate boards for data and wake-up. We are working on the possibility of integrating the two boards for a unified final demo. Modem's power consumption and state changes will be visible on an oscilloscope. For our demo, we initialize the modem into *vigilant sleep* (only wake-up receiver on). A user will then generate an 18kHz tone on a PC connected to an underwater transducer. This will cause our modem to wake-up and transition to an active state; with a visible increase in power drawn. The oscilloscope will also show a modem generated interrupt that is to be used for waking up processors in deep-sleep.

4. REFERENCES

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