Long Island Sound Testbed and Experiments

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Abstract— **To efficiently evaluate the performance of underwater wireless network and develop applications in real environments, an offshore testbed has been developed to conduct field experiments. The testbed consists of four nodes and has been deployed two times in Long Island Sound since Aug 2012. Using this testbed, we evaluated and analyzed the performance of both link and physical layers of an underwater wireless network. The power consumptions of testbed components in different modes were also measured. Experiment data are shared and discussed in details. From the testbed and field experiments, we learn lessons by first-hand experience which will be helpful in improving the testbed and for a better understanding of how underwater wireless networks work in real world scenarios.**

Keywords—underwater wireless network; Long Island Sound testbed; field experiment.

I. Introduction

The earth is a water planet, and two-third of the surface of earth is covered by oceans. Underwater wireless networks (UWNs) are the enabling technology of a wide range of underwater applications, and it has attracted a great amount of interests in recent years [1].

Due to physical characteristics of the underwater channel, the acoustic signal emerges as an alternative to electro-magnetic or optical waves for medium to long range wireless underwater communications [2]. Underwater acoustic channels feature long propagation delay, limited available bandwidth, and high error probability [3]. Many studies have been carried out on underwater acoustic communication [4]-[9]. Due to limitations of channel model based simulations [9], much effort was put into implementing acoustic modems for real UWN systems, and thus various lab and commercial underwater acoustic modems are available. However, since UWNs face needs original designs in almost every component of the protocol stack [3], real system implementation is still challenging. And field experiments are also rare due to technical or non-technical issues, e.g. logistics and budget limitations.

As underwater acoustic channels can be affected by many factors, i.e. noise, multipath and Doppler spread, which are closely related to the environment. The performances of underwater networks are expected to be evaluated in real world scenarios. The field test system Aqua-TUNE [10], a **T**estbed for **U**nderwater **NE**tworks, has been developed to efficiently deploy underwater networks and evaluate performance of protocols and applications. Instead of large buoy systems, Aqua-TUNE project employs small kayaks to carry devices, which provides a convenient platform to facilitate small-scale short-term deployment field experiments.

Furthermore, Ocean-TUNE [11] is proposed as a long-term community ocean testbed system at four different locations, including Long Island Sound, Hood Canal, Santa Monica Bay, and Galveston Bay, which is supported by University of Connecticut, University of Washington, University of California, Los Angeles, and Texas A&M University. Various kinds of underwater network nodes will be employed in this testbed system, including surface nodes employing buoy system, mobile nodes equipped on autonomous underwater vehicle, and bottom nodes fixed on underwater sensor frameworks. The ubiquitous access to underwater testbed systems provided by this project will improve and increase underwater communication and networking researches being performed in future.

As a part of Ocean-TUNE project, four surface nodes have been deployed in Long Island Sound twice during the past year, i.e. from Aug 22 to Aug 27, 2012 and from Dec 20, 2012 to Feb 7, 2013, respectively. We conducted three experiments with this testbed system: performance of an Aloha-based protocol was studied in a MAC layer experiment; packet loss ratios of a recent high performance acoustic modem using OFDM technology were studied in a physical layer test; and power consumptions of different components of the testbed system was measured. We document and share our experience in this paper in hope of being beneficial to the research community and helpful to develop practical UWN systems in real world environments.

The rest of the paper is organized as follows. Section II outlines the hardware configurations of the Long Island Sound testbed surface node. Section III describes the system software developed for the experiments. The designs and results of three experiments are presented in Section IV, V and VI. This paper is concluded in Section VIII after a discussion on field experiment experiences in Section VII.

II. System Hardware

The major system components of a single surface node in the Long Island Sound Testbed are shown in Fig. 1. Most electronics are hosted on a buoy, including an RF modem for remotely controlling from onshore computer, a micro-controller unit (MCU) where the operation system, protocol

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stack and application programs are running, a power distribution board which controls the power supply for MCU and acoustic modems, a battery pack which can be charged by the photovoltaic (PV) panels. Acoustic modems are operated by commands sent from serial port on MCU. The power supply of the acoustic modems and the MCU can be remotely controlled, which is a unique feature of the power distribution board we developed on the buoy.

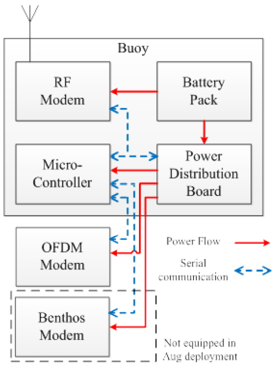

Fig. 1. System chart of surface node

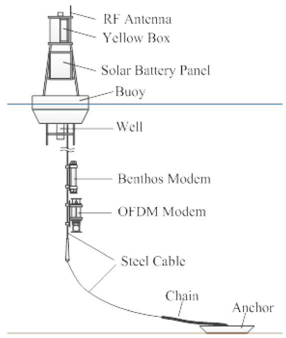

Fig. 2. Mooring system of surface node

As shown in Fig. 2, the mooring system of a Long Island Sound testbed surface node consists of a buoy, an anchor and the steel cable and chain connecting them. The mooring size of the buoy employed in Long Island Sound testbed is about 2000 lbs. There is a 9 feet high tower on the buoy which can be seen in Fig. 3. The RF antenna and a yellow box which contains the RF modem, MCU and power distribution board of a node is fixed on the top part of the tower (see Fig. 3 and Fig. 4). Four PV panels are installed in the middle part of the tower, and the battery pack is contained in the well of the buoy. The acoustic modems are fixed on a 10-meter hard thick steel cable about 5 meters under the buoy. The buoy employs a mushroom anchor and rope-to-chain tether. The total length of the steel cable and chain connecting the buoy and anchor is 160 feet.

Fig. 3. Surface node bouy

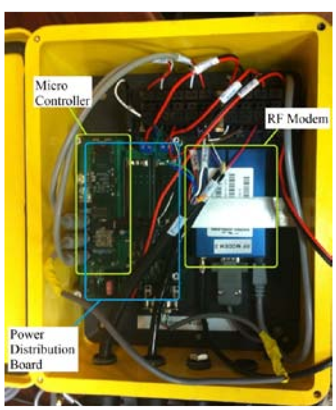

Fig. 4. Surface node electronic compartment

An RF modem [12] is employed to enable remote control from shore. The RF modem performs as a transparent gateway which connects the MCU to the Internet, and each RF modem has a dedicated IP address. Once the RF modem on a node receives a command, it will send this command to both the MCU and power distribution board via serial port. Since Embedded Linux has been installed on the MCU, each Long Island Sound testbed node can be accessed by an onshore computer with remote connect program, i.e. Putty, via the Internet.

The power supply system of a Long Island Sound testbed surface node mainly consists of four 12V 30W photovoltaic panels wired in parallel, a PV junction box, a regulator, five 12V 40Ah lead-acid batteries wired in parallel, a power distribution board and a DC-DC converter. The system chart of power supply system is shown in Fig. 5. All commands transmitted via RF modem could be seen by both the power distribution board and the MCU. By input specific commands for power distribution board in the right way, micro controller and each of the modems can be restarted or shutdown independently.

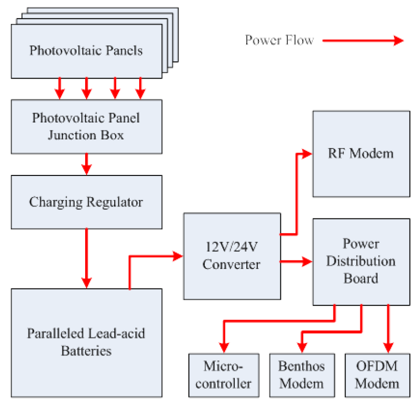

Fig. 5 Power supply system chart

The micro-controller [13] has a fifth generation ARM core, 64MB RAM and 16MB flash memory and runs at a 400MHz main frequency. A 32GB SD card is equipped to store log files and data generated by experiment programs. There are three RS232 ports available on the MCU. One connects to an RF modem to receive commands and send outputs, and the other two connect to two different acoustic modems to perform acoustic communication.

There are two types of acoustic modems employed in Long Island Sound testbed: AquaSeNT OFDM modem [14] and Benthos ATM-885 modem [15]. Each of the nodes is equipped with an OFDM modem, and during the second deployment, three of these nodes are equipped with a Benthos modem as well. Both types of acoustic modem are powered by the power system on buoy, and a 10m 9-Pin watertight cable is employed to provide power supply for each acoustic modem, as well as transmit commands and files between the MCU and acoustic modem.

The Long Island Sound testbed nodes were deployed using the following procedure. First, lower the buoy into water. Then, gradually release steel cable with acoustic modems into water, followed by chain. Meanwhile, ship should keep marching forward to straighten the steel cable and chain. Finally, drop the anchor at the expected deployment location.

III. SYSTEM SOFTWARE

The MCUs run embedded Linux and serve as the software platform for all programs used by the experiments.

Experiment programs, such as the protocol stack, are developed in C code. They are compiled to executable files on PC first and usually saved in SD cards. Linux Shell scripts are also employed to develop experiment programs, because they are easier to debug in imbedded operation system.

In this section, we describe the network protocol stack designed for underwater networks and a protocol developed as a case study for the field test.

A. Aqua-Net

The protocol stack for network experiments on Long Island Sound testbed is based on a Linux implementation of Aqua-Net [16]. Aqua-Net is a powerful architecture for underwater sensor networks which takes both the characteristics of underwater sensor networks and the application needs into consideration.

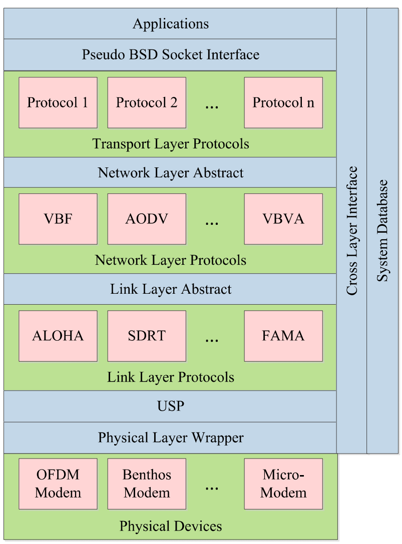

Fig. 6. Layer structure of Aqua-Net

The layered structure of Aqua-Net shown in Fig.6 can make it easy to integrate solutions from different researches. The layered design also enables that Aqua-Net can work with various kinds of acoustic modems. By introducing a translucent layer which is accessible by all layers of application and protocol, Aqua-Net is able to support cross-layer design. Modules for some classic protocols, i.e. UW-Aloha [16], Slotted FAMA [17] have already been developed based on Aqua-Net, which will be useful for comparing performances of naval protocol with classic ones in future.

B. An Aloha-based MAC Protocol

To validate the functionality of this testbed, an Aloha-based medium access control (MAC) protocol was implemented and tested in a series of experiments. MAC is a sub-layer of the data link layer. It provides addressing and multiple access service to the network. The flow chart of this Aloha-based MAC protocol is shown in Fig.7.

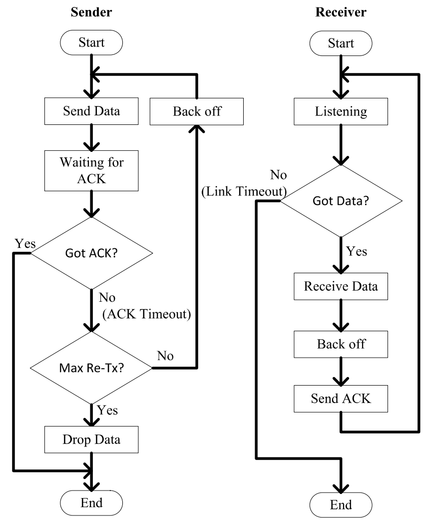

Fig. 7. Work flow for Aloha-based protocol

As the original Aloha protocol, when the sender gets a data packet to send out, it just sends out the packet regardless whether there is any collision. Because sound travels much slower than electrical-magnetic wave, the sender cannot detect collision by simply listening to the channel after sent a packet. As can be seen in Fig.7, besides the original Aloha protocol, acknowledgement (ACK) is incorporated to notice the sender whether the data has been successfully received by the receiver. The receiver will reply an ACK to sender if the data packet has been successfully transmitted. If the sender receive the ACK, it will go on working on next task, otherwise, when ACK waiting times out and there is no ACK received by sender, the sender will retransmit the packet until retransmit time reaches its maximum value. A constant back-off is set before both the sender retransmit a packet and the receiver send out an ACK.

During the experiment, the maximum retransmit time for sender is set to 3. The ACK waiting time is set to 25 seconds.

IV. MAC LAYER EXPERIMENT AND RESULT

The objective of this MAC layer experiment is to study performance of the aforementioned Aloha based MAC protocol in real underwater networks.

A. Deployment Information

The MAC layer experiment began on August 22, 2012 and lasted for 5 days.

As shown in Fig. 8(a), four nodes were deployed close to shore near the Bluff Point State Park. The four nodes formed a square with a side length of 500m. The GPS coordinates of each node can be seen in Fig. 8(a). During this deployment, only AquaSeNT OFDM modems were equipped on each node.

B. Experiment Design

The topology of network was that Node 1 sent massages to Node 3 and Node 2 sent massages to Node 4 simultaneously (see Fig. 6). This topology can represent some scenarios in autonomous underwater vehicle (AUV) networks for cooperative control.

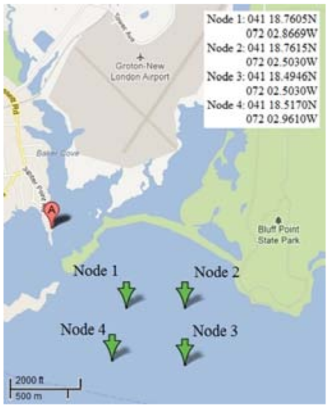

Fig. 8(a). The first deployment

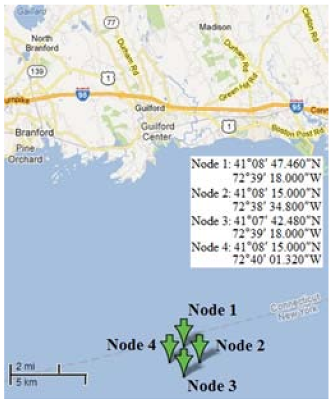

Fig. 8(b). The second deployment

Packet length and data generating rate were taken as parameters of experiments, and throughput was the indicator of protocol performance.

All packets sent in this experiment were generated by an application program. This application program will generate random data packets in specific length according to a Poisson process. The packet length and packet generating rate are two parameters can be specified in different tests.

The packet lengths for two tests were set to 400 Byte and 1000 Byte. According to the design of AquaSeNT OFDM modem, exclusive of the physical layer preamble, there are 16 data blocks at maximum within each packet, and the maximum length of each data block is 80 Byte. Hence, including the prefix and suffix added by protocols in each layer, the packet length cannot exceed 1280 Byte.

The packet generating rate is the average of Poisson process which the number of packets generated by the application program is according to. The transmitting speed of AquaSeNT modem is about 3.1 Kbps. Hence, it takes at least 3 seconds to transmit one 1280B packet. The packet generating rate for each run of this test was among 0.02, 0.065, 0.11, 0.155, 0.2.

To eliminate random errors, the time for each experiment should be long enough to allow the sender nodes send enough packets with each set of parameters. The expectation of packets sent during each run of test with a specific set of parameters is 250. Thus, the time for each run of test with different packet generating rate is as shown in Table I. The total test time for all 5 generating rates and 2 packet lengths is about 12 hours.

TABLE I. MAC LAYER EXPERIMENT SETTINGS AND RESULTS

Packet Generating Rate	Test Time (hour)	Throughput for 2 pairs of nodes (bps)		Packet loss rate for each pair of nodes (%)			
		For 400B cases	For 1000B cases	For 400B cases		For 1000B cases	
				N1 to N3	N2 to N4	N1 to N3	N2 to N4
0.020	3.472	84.74	219.52	26.17	31.08	26.69	25.70
0.065	1.068	109.85	297.53	54.90	57.14	52.82	50.33
0.110	0.631	147.89	316.90	55.14	50.43	52.53	54.26
0.155	0.448	128.95	342.21	58.75	58.97	53.95	54.67
0.200	0.347	143.36	288.00	59.02	53.73	51.67	68.62

C. Results

For each run of test, the throughput is calculated by $R_{ACK} \times L/T$, where R_{ACK} denotes the number of ACK received by sender, and L is the size of each packet (400B or 1000B), and T equals to the test time in seconds. The total throughput of 2 pairs of nodes for each run of test with different settings can be seen in Table I. The throughput of each pair of nodes in each run of test can be seen in Fig.9.

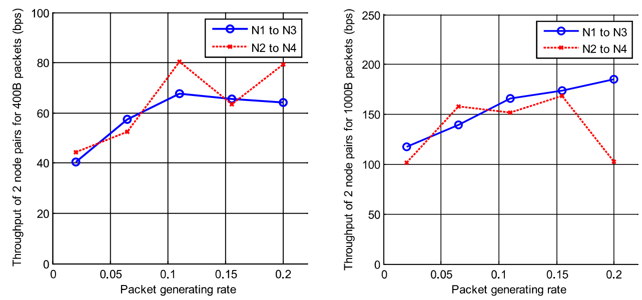

Fig. 9. The throughputs of each pair of nodes for 400B cases(left) and 1000B cases (right)

The packet loss rate is calculated by $(S_{PKT}+S_{RE}-R_{ACK})/(S_{PKT}+S_{RE})$, where S_{PKT} denotes the number of packets sent out by sender, and S_{RE} is the number of retransmitted packets, and R_{ACK} denotes the ACK received by sender. The packet loss rate for each pair of nodes in each run of test can be seen in Table I.

A physical layer test was conducted after this MAC layer test. The result shows that over 99% packets sent by one node can be successfully received by all the other 3 nodes even when the transmit power level is only 0.1% of full power of the OFDM modem. The result of this physical layer test indicates that the packet loss rate should near 0 if there is no collision at the receiver side. Thus, the high packet loss rate shown in Table I should be mainly caused by collisions in the network.

V. PHYSICAL LAYER TEST AND RESULT

The objective of this physical layer test is to collect data for studying the relationship between distance, transmission power level, packet length, and packet loss ratio of the AquaSeNT modem.

A. Deployment Information

The physical layer test began on January 12, 2013 and finally ended on February 6, 2013.

As shown in Fig. 8(b), four nodes were deployed 12 kilometers away from coast in the central part of Long Island Sound. The four nodes located in a diamond formation which 2 miles in diagonal. The GPS coordinates of each node can be seen in Fig. 8(b).

After a blizzard in January, buoy of Node 1 flipped over and all electronic devices on buoy were ruined by sea water. The physical layer test was conducted by Node 2, 3 and 4.

B. *Experiment Design*

Node 4 was set as the sender in this experiment, and it will broadcast packet to both Node 2 and Node 3. The distance between Node 4 and Node 2 was about 2 miles, and the distance between Node 4 and Node 3 was about 1.4 miles.

The transmit power level and packet length will be taken as the variables in this experiment.

The transmit power level of AquaSeNT modem can be set from 0.1% to 100% by specifying a register of AquaSeNT modem. To make the data easier to compare with other types of modems, the transmit power level for each run was set to -3dB, -6dB, -9dB, -12dB, -15dB of the maximum power level, which are 50.1%, 25.1%, 12.6%, 6.3%, 3.2%.

Since the maximum data within one data block is 80 Byte, we set the packet lengths of each run of test to 80 Byte, 640 Byte, 1280 Byte.

It takes more than 3 seconds to send out a 1280B packet. To avoid overwhelming the sender, the sender was set to start sending out one packet every 10 seconds. After send out 20 packets with a specific transmit power level and packet length value, the packet length setting will be change to the next value. After send out 60 packets with a specific transmit power level and 3 packet length settings, the transmit power level setting will change to next value.

C. *Results*

There were 240 packets sent with each specific transmit power level and packet length settings. The packet loss rates can be seen in Table II and Fig.11.

TABLE II. PHYSICAL LAYER EXPERIMENT SETTINGS AND RESULTS

Packet Length (Byte)	80		640		1280	
Packet Loss Rate (%) / **Distance (mile)** / **Transmit Power Level (%)**	1.4	2.0	1.4	2.0	1.4	2.0
50.1	2.08	7.08	3.75	8.75	10.00	16.67
25.1	1.25	17.92	1.25	15.83	4.58	24.58
12.6	0.83	27.92	3.33	30.83	6.67	42.08
6.3	0.83	62.08	2.50	61.25	4.17	61.67
3.2	2.50	85.00	3.75	79.17	9.58	79.17

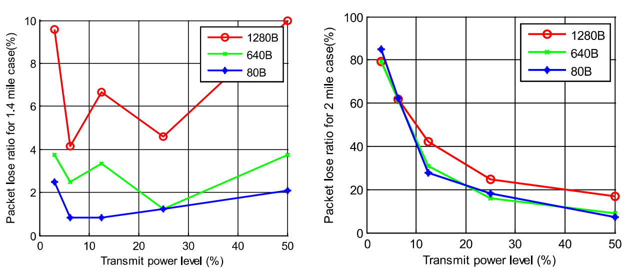

Fig. 11. Packet loss rates for 1.4 mile cases(left) and 2 miles cases(right)

As shown in Fig. 11, the results for 2 miles cases indicate that the packet loss rate increases with a decrease in transmit power level.

VI. POWER CONSUMPTION TEST AND RESULTS

The objective of power consumption test was to obtain power consumption data of each part of the system in different working states.

Although there are 4 PV panels equipped on each Long Island Sound testbed nodes to charge the battery, considering the consumptions caused by acoustic modems, energy is still limited for long term deployment. The data obtained in this test can help planning experiments during a deployment better based on energy budget. Moreover, power consumption waveform can help us know about the systems' working process in detail, for example, the exact time between each two activities of a test, which is useful for developing simulation systems.

Since the parasitic loads within system are not ignorable, we employed a DC power source to instead of the battery pack and took the rest of a node as a system to measure its power consumptions in different working states.

TABLE III. AVERAGE POWER CONSUMPTION FOR DUMMY MODE

Working Devices	**Average Power Consumption (W)**
RF modem	1.085
RF modem, MCU	2.344
RF modem, MCU, Benthos	3.368
RF modem, MCU, AquaSeNT	3.021
RF modem, MCU, Benthos, AquaSeNT	3.441

As shown in Table III, when there is no experiment program running, the power consumption is related to the number of devices which are turned on.

It takes 288.61J to start up the MCU and complete the initialization of operation system. When there are messages sending out from the node via RF modem, the average power consumption is 3.684W.

The average power consumption is calculated by dividing the total energy consumed by total time of sending or receiving a packet. The average power consumption for receiving messages from Benthos modem is 3.363W. For receiving messages from AquaSeNT modem, it's 3.539W. The average power consumptions for sending out messages with some transmit power levels can be seen in Table IV.

TABLE IV. AVERAGE POWER CONSUMPTION FOR SENDING PACKETS

Ave. Power Consumption (W) / **Transmit Power Level (%)** / **Modem Type**	50	25	12.5	6.3	3.2
OFDM Modem	28.89	19.22	14.61	12.49	11.05
Benthos Modem	19.77	12.74	9.00	6.43	5.33

Although the average power consumption for AquaSeNT modem is higher than that of Benthos modem, due to much higher data rate in the challenging environment, AquaSeNT modem has more energy saving than the Benthos modem. For example, it takes about 160.61J to send out an 800B packet at 50% transmit power level by Benthos modem, while it only takes 64.65J by the AquaSeNT modem.

VII. DISCCUSIONS

In order for a successful sea test, the deployment locations should be chosen properly. During the first deployment in August, the locations were close to shore. Different from the second deployment, the acoustic channel during first deployment were very good. Therefore physical layer experiments didn't show much variance in terms for packet error rate under different settings. However, during the second deployment, the locations were too far away from coast for the RF communication. Moreover, if possible, it is recommended to run a one or two days' dry run deployment before start a long term deployment. Both the RF and acoustic channel need to be double checked at the candidate deployment locations.

All electronics within the network nodes should be protected in water tight containers. In our experiment, the yellow box containing the electronics is on top of a 7-feet high tower on a 2000-lb buoy. The box was only designed to provide protection in rains and waves. However, one node was found capsized after a blizzard during the second deployment, and the seawater got into the yellow box. That caused serious damages to the MCU, RF modem and power distribution board. Thus, the testbed was not able to run any protocol test during the second deployment after that.

Power consumption caused by parasitic loads can become a big problem for large nodes as are used in the Long Island Sound testbed. The parasitic loads will not only shorten battery life, but also cause partial flash out of a node. For example, the voltage drop caused by the 15m watertight cable connecting the acoustic modem and buoy can cause flash out of acoustic modems. The battery pack provides 24V DC power supply to the modem, and the acoustic modem will shut down when voltage of power supply is lower than 16V. However, the modem instantaneous current can be as high as 8A when sending out packet with full power, and the voltage drop along the 15m watertight cable will reach 8V. Consequently, the acoustic modem could suddenly flash out during or after sending out a packet and restart itself immediately.

VIII. CONCLUSION

The Long Island Sound testbed is our effort of providing field experiment experience to the research community. It can be used to efficiently evaluate the performance of underwater wireless networks in real world scenarios with actual devices. With this testbed, a number of experiments have been conducted since Aug 2012. This paper aims to document our efforts and share our experience with the research community. We hope our experience of the Long Island Sound testbed and field experiments could be beneficial to fellow researchers and help in developing practical and high performance UWN systems in real environments.

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REFERENCES

[1] A. Baggeroer, "An Overview of Acoustic Communications from 2000-2012", in Underwater Communications: Channel Modelling & Validation, 2012.

[2] Jim Partan, Jim Kurose, and Brian Neil Levine. 2006. "A survey of practical issues in underwater networks". In *Proceedings of the 1st ACM* international workshop on Underwater networks (WUWNet '06). ACM, New York, NY, USA, 17-24.

[3] Jun-Hong Cui, Jiejun Kong, Mario Gerla, and Shengli Zhou. "Challenges: Building Scalable Mobile Underwater Wireless Sensor Networks for Aquatic Applications". IEEE Network, 20(3):12–18, 2006.

[4] Stojanovic, Milica. "On the relationship between capacity and distance in an underwater acoustic communication channel." ACM SIGMOBILE Mobile Computing and Communications Review 11.4 (2007): 34-43.

[5] Xiaoka Xu, Shengli Zhou, Andrey K. Morozov, and James C. Preisig, "Per-survivor processing for underwater acoustic communications with direct-sequence spread spectrum," J. Acoustical Society of America, vol. 133, pp. 2746-2754, May 2013.

[6] Chitre, Mandar, et al. "Recent advances in underwater acoustic communications & networking." OCEANS 2008. Vol. 2008. IEEE, 2008.

[7] Kilfoyle, Daniel B., and Arthur B. Baggeroer. "The state of the art in underwater acoustic telemetry." Oceanic Engineering, IEEE Journal of 25.1 (2000): 4-27.

[8] Xiaoka Xu, Zhaohui Wang, Shengli Zhou, and Lei Wan, "Parameterizing both path amplitude and delay variations of underwater acoustic channels for block decoding of orthogonal frequency division multiplexing," Journal of the Acoustical Society of America, vol. 131, no. pp. 4672- 4679, June 2012.

[9] Stojanovic, Milica, and James Preisig. "Underwater acoustic communication channels: Propagation models and statistical characterization."Communications Magazine, IEEE 47.1 (2009): 84-89.

[10] Zheng Peng, Son Le, Michael Zuba, Haining Mo, Yibo Zhu, Lina Pu, Jun Liu and Jun-Hong Cui., "Aqua-TUNE: a Testbed for Underwater Networks", in Proc. MTS/IEEE Oceans, Santander, Spain, Jun. 2011.

[11] Jun-Hong Cui, Shengli Zhou, Zhijie Shi, James O'Donnell, Zheng Peng, Mario Gerla, Burkard Baschek, Sumit Roy, Payman Arabshahi, and Xi Zhang. "Ocean-TUNE: A Community Ocean Testbed for Underwater Wireless Networks". In Proc. of the Seventh ACM International Conference on Underwater Networks and Systems (WUWNet'12), Nov 2012.

[12] AirLink Raven XT RF modem, Sierra Wireless, http://www.sierrawireless.com/en/Newsroom/productimages/ProductImages_AirLink/airlink_ravenxt.aspx, 2013.

[13] Gumstix, 2004-2012 Gumstix inc, https://www.gumstix.com/, 2013.

[14] H. Yan, L. Wan, S. Zhou; Z. Shi, J.-H. Cui, J. Huang, H. Zhou, "DSP based Receiver Implementation for OFDM Acoustic Modems", Elsevier Journal on Physical Communication, 2011 2011; doi:10.1016/j.phycom.2011.09.001.

[15] Benthos ATM-885 acoustic modem, Teledyne-Benthos, ACOUSTIC MODEMS, http://www.benthos.com/index.php/sea_stories, 1999.

[16] Zheng Peng, Zhong Zhou, Jun-Hong Cui and Zhijie Shi, "Aqua-Net: An Underwater Sensor Network Architecture: Design, Implementation, and Initial Testing", in Proc. IEEE/MTS OCEANS, Biloxi, MS, Oct. 2009.

[17] Molins, Marcal, and Milica Stojanovic. "Slotted FAMA: a MAC protocol for underwater acoustic networks." OCEANS 2006-Asia Pacific. IEEE, 2007.