Power Management for Acoustic Underwater Networks

Iyad Tumar, Anuj Sehgal, Jürgen Schönwälder

School of Engineering and Science

Jacobs University Bremen

Campus Ring 1, 28759 Bremen

{i.tumar, s.anuj, j.schoenwaelder}@jacobs-university.de

Abstract—As a result of the large area to be monitored in most underwater sensor network applications, many acoustic networks have a sparse topology. The underwater acoustic channel characteristics can cause power consumption of nodes to be quite high. This paper presents information on a work in progress to design a power management scheme for asynchronous node communication to maximize the power efficiency of such an acoustic underwater network. The proposed scheme takes advantage of the propagation delays introduced by the underwater channel and relies on the usage of a high-power and a low-power acoustic modem to perform the data exchange. While the high-power modem is used to achieve high-bit-rate data exchange between nodes, the low power modem is used for node discovery. This paper presents some background information and preliminary experiments carried out along with details on the proposed power management scheme.

I. Introduction

Underwater sensor networks find applications ranging from oceanographic research, surveillance systems, navigation, off-shore exploration to disaster prevention and environmental monitoring as well.

The underwater communication channel is not conducive to using radio frequency (RF) for communication between sensor nodes as radio waves can only propagate through sea water at very low frequencies (30-300Hz) [1]. However, wireless connectivity between devices is achieved using underwater acoustic networking [1]–[3]. Though these acoustic networks enable the use of wireless networks in a host of applications for the underwater environment, the acoustic underwater networks pose some very important challenges to achieve real-time communications in the form of limited bandwidth capacity, limited battery power availability with none to little possibility of recharging and the likelihood of network disruptions [4].

To achieve the largest possible area of coverage a 3-dimensional sensor network is most likely to have a sparse topology [1]. Therefore, it is essential to address the issue of power management and to design a scheme that would best utilize the characteristics of this medium to maximize the network lifetime.

Since the underwater acoustic channel introduces long propagation delays, which are also augmented by the sparse network topology, it is possible and desirable to introduce sleep cycles into the operation of the transceiver array in order to maximize the life of the node [1], [5]. Using this ideology

as a base we propose in this paper a power management scheme for asynchronous data communication that puts to sleep the data communication modem in order to conserve power. However, unlike most works we propose to equip the nodes with a high-power modem, capable of high data rate exchanges, and a low-power modem, for low data rate exchanges.

The rest of this paper is structured as follows: Related work is discussed in Section 2. In Section 3 we present some preliminary data. Section 4 provides insights on the research questions raised by related studies and our proposed approach to solving these. We end in Section 5 with information on the future work that provides insight into the metrics and methods we will use to evaluate the proposed scheme.

II. Related Work

As shown in [1], [2] there is a lot of research on underwater acoustic networking in the recent years, most of which has been in the area of investigating the physical, data-link, network and transport layers; this however leaves the problem of power efficiency for underwater acoustic networks not addressed enough. The authors of [6] highlight the need for developing algorithms to specifically maximize energy efficiency in sparse underwater acoustic networks in order to facilitate long term deployments of such networks since once a network is deployed the issue of limited battery resources becomes particularly important as a result of the difficulty and high cost associated with recharging node batteries [7].

The work presented in [7] addresses the power efficiency issue by exploring the effects of multiple topology types on the power consumption and network lifetimes. The optimizations recommended in this work are based upon specific topologies and this approach can fall short of addressing all needs since the application in consideration may require a specific topology that is not very power efficient. As such, though useful this approach is not very flexible and presents the need for a topology free power management scheme. The authors of [6] present arguments that there are significant differences between underwater acoustic modems and radio transmitters that make idle-time power management methods designed for radio communications not very suitable for applications in the underwater environment. In their work the authors compare multiple idle-time power management techniques ranging from

no sleep or wakeup state modes, an optimal sleep mode and a wakeup mode protocol. Their further work discussed in [8] uses a single acoustic modem with an ultra low power low bit rate mode that is used purely in listening mode in order to conserve power and switches to either a high bit rate or low bit rate receive and transmit mode. The authors of the paper recommend using the wakeup mode and switching between high power and low power transmit/receive modes for the acoustic modem. Though this provides the flexibility of achieving high bit rates, the transition time between modes can lead to large delays, which are not desirable. Also, the work, while addressing sleep-cycle based power efficiency in underwater networks does not focus on disruption tolerance and the likely sparse topology, especially in deep water scenarios, thereby, creating the need for exploring such similar protocols as well.

Achieving power efficient high bit rate communications underwater is of high importance since most existing acoustic modems provide either a very low bit rate or a high bit rate with a very high power consumption. To overcome this shortfall the authors of [9] have designed underwater sensor nodes equipped with an acoustic modem for low data rate and also an optical modem for high data rate in shallow water dense topology conditions. The method of switching between the acoustic modem and the optical modem to achieve the desired bit rate is effective in reducing the mode change time of the method proposed in [8] but the use of an optical method restricts the range of high bit rate communication to very short distances since optical data transfer methods do not work reliably over long ranges, if at all, underwater. The power management scheme presented in the following sections of this paper aims to overcome the shortcomings of the methods used in [6]–[9]:

1) It is designed independent of the network topology being used.
2) By using two acoustic modems it is not susceptible to a long delay in switching modes between high-power and low-power transmit/receive

III. PRELIMINARY RESULTS

As discussed in the previous section, the related work in the area of underwater acoustic communications already points towards the need to develop an efficient power management scheme that ensures maximum lifetime of the network and also at the same time achieves the most time efficient way of transmitting data over long distances. Our proposed approach to solve this problem is to utilize a high power modem for data transfers while using a low power modem for transmitting beacons to enable neighbor discovery.

In order to further strengthen our case for development of a power management scheme following this pattern, we utilized the underwater simulation environment toolkit provided for ns-miracle by the authors of [10]. In our simulation we compared the power usage of a high power modem with that of a low power modem. For this purpose we utilized the properties of the WHOI Micromodem, as shown in Table I, since it provides both, a high power and low power mode.

We simulated a network consisting of 8 underwater nodes transmitting beacons of 4 and then 8 bytes using BPSK modulation. The nodes are distributed randomly such that the maximum distance between any of the nodes is 1 km. For our simulation the nodes are kept stationary. In order to achieve an indication of whether a high power or low power modem is suitable to a certain task, we set up the nodes to transmit beacons with a time period of one second and 50% duty cycle.

Figure 1 depicts the total power consumed by a single node in the network while the nodes are transmitting and receiving beacons in broadcast mode. It is clear from this graph that power utilization for the high power modem for sending and receiving beacons is magnitudes higher than that of the low power modem.
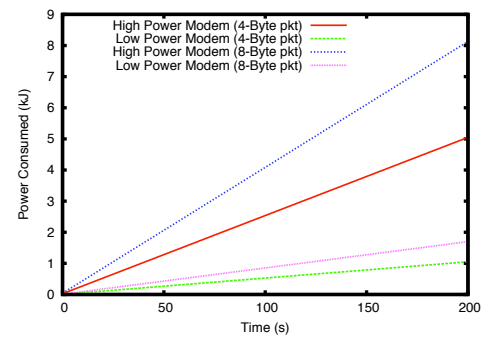

Fig. 1. Total power consumed by a single node to transmit and receive beacons.

In order to determine which modem would be appropriate to transmit data we plot the power consumed to transmit data of varying sizes in Figure 2 using different data sizes. As is clear in this graph, the high power modem consumes lesser power than the low power modem and this difference increases as the amount of data to be transmitted increases. This appears to be the case because the high power modem achieves a much higher transmission bit rate as compared to the low power modem and as such consumes lesser power for data transmission, thereby making it suitable for data exchanges.
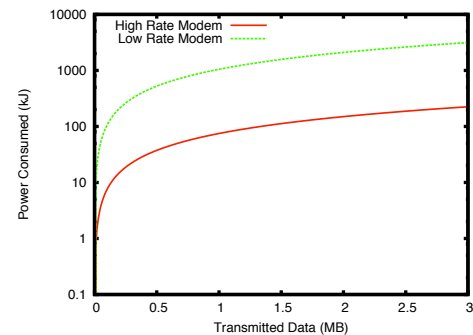

Fig. 2. Power consumed to transmit data by a single node.

These results reinforce that our proposed approach of transmitting data using the high power modem and using a low

Name	Tx Power	Rx Power	Type	Data Rate
WHOI	50 Watt	3 Watt	High Power	5600 bps
WHOI	10 Watt	80 mWatt	Low Power	80 bps

power modem to transmit beacons for neighbor discovery should provide considerable power savings.

IV. RESEARCH ISSUES AND PROPOSED APPROACH

The on-going work presented in this paper aims to develop a new power management scheme for sparse disruption underwater acoustic networks that saves energy and extends the network life time with minimum reduction of the network connectivity opportunities. The research issues that need to be addressed in order to achieve this goal are:

1) What are the efficient approaches to saving energy in sparse underwater acoustic networks with the minimum possible degradation of network performance?
2) What impact does traffic load have on the power management scheme in underwater acoustic networks?

Our approach combines the on-demand and asynchronous schemes of data communication. It uses a low power acoustic modem emitting beacons periodically to search for contacts within its neighborhood and remaining in sleep mode for the rest of the time. A high power acoustic modem remains in sleep mode until there is data ready to be delivered or received from another node. Once data exchange has taken place this high power acoustic mode once again enters sleep mode. As such, two alternative operations are considered in this scheme:

1) Neighbor discovery in which a node wakes up to search about neighbor nodes for data forwarding.
2) Data delivery in which data is exchanged among nodes.

It is deduced in [1], [2] that time synchronization between acoustically networked underwater nodes is extremely difficult to achieve due to the long and varying propagation delays that are introduced due to the channel characteristics of the underwater environment. As such, our proposed scheme allows each node to work on its own wake up schedule thereby overcoming the need to have synchronized clocks. Each node in our approach uses a fixed duty cycle. Within this duty cycle, each node wakes up for a fixed or adaptive period and sleeps for the rest of the time. We assume that there will be overlapping active periods between nodes within a certain number of duty cycles. The energy consumption of computations is not taken into consideration; we only consider the energy consumption of the acoustic interfaces in discovery mode as well as in data exchanges mode.

V. FUTURE WORK

This paper motivates and outlines a new power management scheme for sparse acoustic underwater networks. We formulate the research questions and outline a novel power management scheme combining on-demand and asynchronous schemes. This scheme is being implemented and evaluated by simulation in the ns2 simulator. We will investigate the impact of our power management scheme on the delivery ratio and the delivery delay under different traffic loads. The following metrics will be considered:

1) The Delivery Ratio is the amount of successfully received data over the total amount of delivered data.
2) The Delivery Delay is the average delay per delivered message.
3) The Energy Cost is the total energy consumption in the network for various traffic patterns.
4) The Node Lifetime is to evaluate the time to first node death (or more generally the time until a given percentage of nodes die), which corresponds to evaluating the maximum energy consumption across nodes.

The achieved results will also be compared against other prominent power efficiency schemes, especially the ones presented in Section 2 of this paper. At the conclusion of the on-going work we hope to have developed a disruption tolerant asynchronous data communication power management scheme that enables high data rate communication.

VI. ACKNOWLEDGEMENT

REFERENCES

[1] I. Akyildiz, D. Pompili, and T. Melodia, "Underwater acoustic sensor networks: research challenges," *Elseviers Ad Hoc Networks*, vol. 3, no. 3, 2005.
[2] I. F. Akyildiz, D. Pompili, and T. Melodia, "State-of-the-art in protocol research for underwater acoustic sensor networks," in *WUWNet '06: Proceedings of the 1st ACM international workshop on Underwater networks*. New York, NY, USA: ACM, 2006, pp. 7–16.
[3] J. Proakis, E. Sozer, J. Rice, and M. Stojanovic, "Shallow water acoustic networks," *IEEE Communications Magazine*, vol. 39, no. 11, pp. 114–119, 2001.
[4] E. Sozer, J. Proakis, R. Stojanovic, J. Rice, A. Benson, and M. Hatch, "Direct sequence spread spectrum based modem for under water acoustic communication and channel measurements," *OCEANS '99 MTS/IEEE. Riding the Crest into the 21st Century*, vol. 1, pp. 228–233, 1999.
[5] A. Sehgal, I. Tumar, and J. Schönwälder, "Variability of available capacity due to the effects of depth and temperature in the underwater acoustic communication channel," in *OCEANS 2009 MTS/IEEE, Bremen, May, 2009. (to appear)*.
[6] A. Harris, M. Stojanovic, and M. Zorzi, "Idle-time energy savings through wake-up modes in underwater acoustic networks," *Ad Hoc Networks In Press, Uncorrected Proof, Available online 6 September 2008. (http://www.science-direct.com/science/article/B7576-4TCR1SR-1/2/2344f0dc986d7e5bc60cdc8509390961)*, 2006.
[7] R. Jurdak, C. V. Lopes, and P. Baldi, "Battery lifetime estimation and optimization for underwater sensor networks," *IEEE Sensor Network Operations*, vol. Winter, 2004.
[8] A. Harris, M. Stojanovic, and M. Zorzi, "When underwater acoustic nodes should sleep with one eye open: idle-time power management in underwater sensor networks," in *WUWNet '06: Proceedings of the 1st ACM international workshop on Underwater networks*. New York, NY, USA: ACM, 2006, pp. 105–108.
[9] I. Vasilescu, C. Detweiler, and D. Rus, "Aquanodes: an underwater sensor network," in *WuWNet '07: Proceedings of the second workshop on Underwater networks*. New York, NY, USA: ACM, 2007, pp. 85–88.
[10] A. F. Harris and M. Zorzi, "Modeling the underwater acoustic channel in ns2," in *ValueTools '07: Proceedings of the 2nd international conference on Performance evaluation methodologies and tools*. ICST, Brussels, Belgium: ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), 2007, pp. 1–8.