Adaptive Underwater Acoustic Communications

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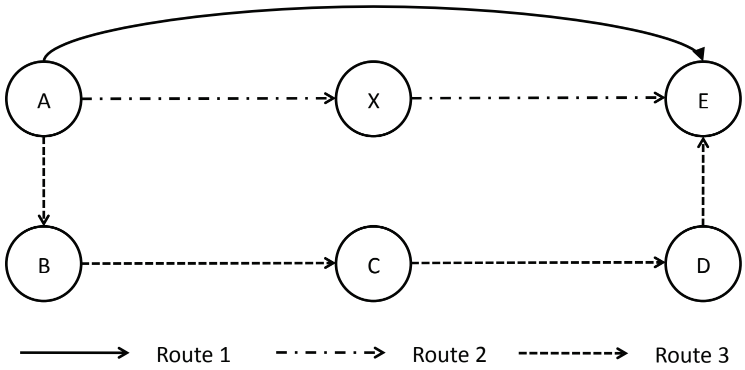
Abstract. Underwater wireless networks consist of mobile and static nodes, which usually communicate using the acoustic channel since radio transmissions attenuate rapidly and optical communication is only suitable for short distances. The underwater acoustic channel is plagued with issues of high transmission power requirements, rapidly changing channel characteristics, multi-path echoes, possible high ambient noise, high and varying propagation delays. To achieve optimal performance an underwater network must be able to sense its ambient environment and react by adapting its communication parameters. This paper proposes to take a two-tier approach in order to develop adaptive underwater communications; by developing an adaptive routing protocol that reacts to environmental parameters and developing a software acoustic modem to enable lower layer adaptations as well.

Keywords: Underwater Acoustic Networks, Underwater Acoustics, Software Modems, Environmental Adaptive Routing

1 Introduction

Communication using the radio channel is not efficient underwater since radio waves attenuate quickly. The only radio systems which are usable underwater are those which use very low transmission frequencies (30-300 Hz), very long antennae and high transmission power. Optical communication is usable for very short range communication owing to the high level of attenuation the visual spectrum experiences in the aquatic medium [1]. As such, the acoustic channel is used commonly to achieve wireless communications in the underwater environment.

Underwater acoustic transmission suffers from a number of issues due to the volatility of channel conditions. High and varying ambient noise and multipath echoes create challenges for dependable communication in the underwater acoustic channel. While it is widely accepted that the underwater acoustic channel suffers from low-transmission speeds, narrow bandwidth, high transmission power requirements and high bit-error-rates, high localized fluctuations in propagation delay due to the dependence of sound velocity on ambient temperature, salinity and acidity also add to the complexities of the channel. It is necessary to build cross-layer adaptive systems for optimal underwater acoustic communications. The work proposed in this paper is aimed at the routing and physical layer.



	Capacity (bps)	Average SNR (dB)
Route 1 (Single Hop)	0.1797	11.80
Route 2 (Multi Hop)	0.4429	7.68
Route 3 (Multi Hop)	1.0002	3.70

Fig. 1. A sample underwater topology with node A transmitting to E, 2 km apart at 500m depth. Node X is at 1 km distance from A and at 500 m depth. Nodes B, C, D are located at 1 km depth with 1 km distance between them. The table shows some performance metrics of this network. Signal transmission properties of 30 kHz at 80 dB strength and 2 kHz bandwidth are used.

Though software acoustic modems were initially proposed as an approach to tackle the high cost [2] of hardware for this environment, this approach may also be used in order to build adaptive acoustic modems which could change the coding and modulation methods in agreement with all nodes. An adaptive routing protocol that can sense environmental parameters is also necessary in order to fully optimize the network performance. This paper presents the research questions of relevance to this study, followed by some related research work and conclusions.

2 Research Questions and Proposed Approach

Communication in the underwater acoustic channel imposes a dependence between achievable data-rate and the transmission distance, depth, frequency and transmission power [3,4]. From Figure 1 it becomes clear that using a multi-hop approach and preferring deeper routes provides greater reliability and transmission capacity. Increasing transmission distance and shallow water communications introduce a high bit-error-rate (BER) and signal-to-noise ratio (SNR). It can also be shown that temperature, salinity and acidity of the ambient environment have a pronounced effect on channel bandwidth, BER and SNR [5]. As such, the research questions of interest to this study are:

1. *How much performance increase can be obtained by mitigating effects of ambient temperature, salinity and acidity, by prefering shorter and deeper hops?*

2. *What is the effect of packet sizes on the reliability, energy consumption and throughput of such networks? Does there exist an optimal packet size and should it be adapted according to ambient conditions as well?*
3. *How can performance be improved by adapting channel coding and modulation methods during run-time to suit the channel characteristics? If so, what parameters must be considered to optimize performance?*
4. *What effect does node mobility have upon the performance of such a network? How might any negative effects be mitigated?*
5. *What are the efficient ways of having the entire node swarm agreeing upon communication parameters in a low-power lossy network plagued with frequent partitions?*

The proposed approach combines an adaptive routing protocol which reacts to the ambient environment and a software acoustic modem capable of changing its characteristics at run-time. The proposed protocol (and modem) will need access to external data, such as, node depth, temperature, salinity and acidity. This can be easily derived from sensors on each node. An ultra-short baseline (USBL) tracking system for global localization or a two-way round trip time measurement system for inter-node localization can be used for distance measurements.

The routing protocol will be analyzed in the underwater communications simulator designed for this study [5]. The software modem, being designed using GNURadio, will be configured with a transmitter and receiver pair; a software layer will model parameters such as ambient noise in order to study effects of conditions which are not mathematically modelable. This test-bed could also be used to study the effects of changing modulation and coding mechanisms on the performance of the communication system.

The metrics considered by this study will include delivery ratio, propagation delay, SNR, BER, bandwidth, transmission power, energy consumption and end-to-end throughput. The 2D and 3D network topologies discussed in [1] will be used as the basis for the testing scenarios.

3 Related Work

A few routing protocols have been proposed for underwater networks. The Vector Based Forwarding (VBF) protocol [6] aims to solve the problem of high error probability in dense underwater sensor networks by defining a routing pipe from the source to the sink and causing floods inside the pipe. In [7] a two-phase routing solution for long-term monitoring missions based on centralized planning of network topology and data-paths is introduced. A Depth Based Routing (DBR) protocol was proposed in [8] which always attempts to forward data to a node that is geographically located above itself. These protocols are not applicable in ad hoc underwater networks as they are designed for specific node-sink communication scenarios.

Some effort has also been placed into designing software acoustic modems for underwater communication [9,10]. Most of these developments have concentrated on using waterproofed TinyOS motes with microphones and speakers to set up an underwater network. However, even though this lowers costs of underwater networks it does not provide enough resources to develop reliable systems which could be used in real world communications.

4 Summary

We proposed developing an adaptive routing protocol and a software modem in order to improve the efficiency of underwater acoustic communications. Important research questions were formulated and a brief outline of the development, testing and evaluation approach, along with related work, has also been provided.

Acknowledgement

The work reported in this paper is supported by the EC IST-EMANICS Network of Excellence (#26854).

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