

Energy Efficient Optimal Path Transmission in Underwater Sensor Networks Using CDMA Based MAC Protocol

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Abstract. Underwater sensor network consists of a variable number of sensors deployed to perform collaborative monitoring tasks. Due to the long propagation delay and high error rate of acoustic channels, it is very challenging to provide reliable data transfer. On the one hand, traditional retransmission upon failure usually introduces very large end-to-end delay. Multipath power-control transmission guarantee certain end-to-end packet error rate while achieving a good balance between the overall energy efficiency. It combines power control with multipath routing and packet combining at the destination. Multipath selection is done by optimizing the transmitting power using constraints path length and no of paths. Under water sensor nodes, which are working on the basis of battery power, may not have constant processing time. The chance of occurring interference and collisions among sensor nodes is more. In this paper, multipath power control transmission scheme is integrated with CDMA based distributed MAC protocol.

Keywords: wireless sensor networks, underwater wireless sensor networks, medium access control, code division multiple access, quality of service, request to send, clear to send.

1. Introduction

Underwater sensor network enable a wide range of aquatic applications, such as oceanographic data collection, pollution monitoring, offshore exploration, and tactical surveillance applications. On the other hand, the adverse underwater environments pose grand challenges for efficient communication and networking.

In underwater environments, radio does not work well due to its quick attenuation in water. Thus, acoustic channels are usually employed. The propagation speed of acoustic signals in water is about 1.5×10^3 m/s, which is five orders of magnitude lower than the radio propagation speed 3×10^8 m/s. Moreover, underwater acoustic channels are affected by many factors such as path loss, noise, multipath fading, and Doppler spread. All these cause high error probability in acoustic channels. In short, underwater acoustic channels feature long propagation delay and high error probability. In such harsh network scenarios, it is very challenging to provide energy-efficient reliable data transfer for time-critical applications. Compared to its terrestrial counterpart, underwater sensor network is even more energy-constrained since underwater nodes are typically powered by batteries, for which replacement or recharging is very difficult.

Multipath power-control transmission (MPT), combines power control with multipath routing and packet combining at the destination. No hop-by-hop retransmission is allowed in MPT, as that contributes to the low end-to-end delay. Specifically in MPT, the source node transmits the same packet along multiple paths to the same destination. The transmission power at each intermediate node along each path is controlled by the source nodes based on the path characteristics. Multiple copies of the packet will arrive at the destination along different paths, and the destination then recovers the packet by combining the received copies. Packet-combining techniques such as those in [8], [11], can be used here.

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Due to the wireless mode of communications in UWSNs, the nodes are vulnerable to the hidden/exposed terminal problems that are intrinsic of ad hoc networks which communicate via a shared medium without centralized control. To alleviate the complications associated with the hidden/exposed nodes in terrestrial wireless networks, various multiple access techniques such as TDMA, FDMA and CDMA, as well as their variants/combinations have been established. While there have been vast research efforts dedicated to improve the Quality of Service (QoS) support in terrestrial wireless ad hoc networks at the Medium Access Control (MAC) layer. Under water sensor networks are more resource-constrained (in terms of energy and bandwidth) and suffer from long propagation delays that are at least five orders of magnitude of their terrestrial counterparts. Also, temporal property of underwater links makes the network more predictable in terms of reliability and resource availability.

Consequently, suitable access schemes have to be developed to enable efficient communication in underwater wireless environments. In the literature, there are increasingly more research efforts that focus on designing MAC protocols for underwater communications. However, most of these protocols still employ RF channel acquisition methods such as carrier sensing; hence they may not be very efficient in underwater acoustic environments with particularly low bandwidths, variable delays and severe energy constraints. In this paper, distributed MAC Protocol for Long-latency Access Networks can be used for half-duplex wireless sensor networks. CDMA is used as the underlying multiple access technique due to its collision-free and multipath-resilient properties.

The work can be viewed as twofold. First, a novel and effective multipath transmission scheme for time-critical applications in underwater sensor networks. It can improve the overall energy efficiency across the whole network with low end-to-end delay and high reliability. Then, implementation of distributed CDMA based MAC protocol on MPT.

2. Related work

A key reason why current terrestrial Radio-Frequency (RF) based MAC protocols [3][4][5] cannot be directly used in UWSNs is that they do not cater for the harsh physical characteristics of the underwater channel. There are a few proposed frameworks for underwater sensor MAC protocols, but generally very little analysis and research that explores their suitability in underwater networks. In general, MAC protocols can be classified as deterministic (e.g. TDMA and FDMA) or non-deterministic (e.g. ALOHA, CSMA, MACA, MACAW and IEEE 802.11). The latter is also known as random access protocols, which are contention-based in nature, i.e. nodes compete to transmit data at various times and access to the channel is not guaranteed. As such, contention-based protocols are unable to provide the QoS guarantees required by real-time data transmissions.

2.1. Multiple access techniques

All The three types of multiple access techniques are TDMA, FDMA and CDMA. In TDMA, only one user is granted channel access at any one time; any other node attempts to transmit during the same time slot will result in collisions and packet losses. The main problem of utilizing TDMA schemes in UWSNs is that the communication channel is susceptible to long and variable propagation delays. FDMA is also unsuitable for underwater environments due to the limited bandwidth as well as prevalence of multi-path and fading effects. The use of CDMA in UWSNs has been advocated due to its resilience to multi-path and Doppler effects [6]. In Direct Sequence (DS) CDMA systems, each node encodes its signal with a unique pseudo-random noise codeword (PN sequence) before transmitting. The transmitted signal is spread over a larger bandwidth as compared to the original non-spread bandwidth. This spread-spectrum technology that is being adopted by CDMA allows multiple nodes to transmit concurrently within the same time or frequency dimension, which are not achievable using TDMA or FDMA techniques. Hence, CDMA techniques are able to provide more capacity than other multiple access techniques due to their collision-free properties. In addition, CDMA is resilient to Doppler's effects and variable propagation delays, which are prevalent in UWSNs.

Majority of the existing underwater MAC protocols adopt the handshaking protocol that was originally proposed in MACA (Multiple Access with Collision Avoidance). In MACA, a three-way handshake

involving the exchange of RTS-CTS-DATA is used to establish connectivity between source-destination pairs. Some proposed protocols incorporate power control and ARQ (Automatic Repeat Request) mechanisms to improve reliability and performance.

3. CDMA Based MAC Protocol

In this section, we provide the details of distributed CDMA-based MAC Protocol.

- RTS (Request-To-Send): A node that has unicast data packets to send will transmit a RTS to its intended destination.
- CTS (Clear-To-Send): Upon receiving a RTS packet from its neighbour, the node will respond with a local broadcast CTS packet after a finite waiting time.

CDMA based MAC protocol makes use of the RTS-CTS dialogue, with the main difference being that multiple RTS packets from different source nodes (S1, S2 and S3) are collated by the destination node D before the transmission of a single CTS (broadcast) packet (see Figure 1). In this way, CDMA-based systems can receive concurrently from multiple sources which utilize different code words, and thus improve the network throughput while minimizing packet losses arising from unsynchronized data transmissions. Another advantage is that it reduces the number of control packets being sent, by sending one CTS for a few accumulated RTS packets, in contrast to conventional MACA-based schemes which send one CTS for each received RTS. Consequently, the energy consumed by the nodes is also reduced.

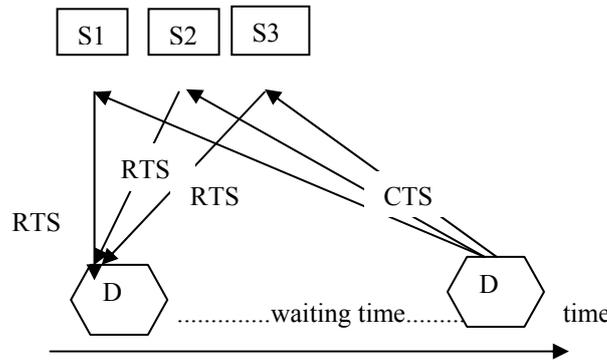


Fig. 1: Handshaking in CDMA based MAC protocol

4. Network Model

Underwater sensor nodes with acoustic modems are densely distributed in a 3-D aqueous space, and multiple gateway nodes with both acoustic and RF modems are strategically deployed at the water surface. Each underwater sensor node can monitor and detect environmental events locally. As shown in Fig. 2, when an underwater sensor node has data to report, it first transfers the data toward one or multiple surface gateway nodes (each is also referred to as a sink) through acoustic links. Then, these surface gateway nodes relay the received data to the control center through radio links. Compared to the acoustic links in water, surface radio links are much more reliable, faster, and more energy-efficient. In addition, gateway nodes are usually more powerful and have more energy supplies. In this way, the multisink network architecture is helpful in traffic balance and multiple-path finding [12].

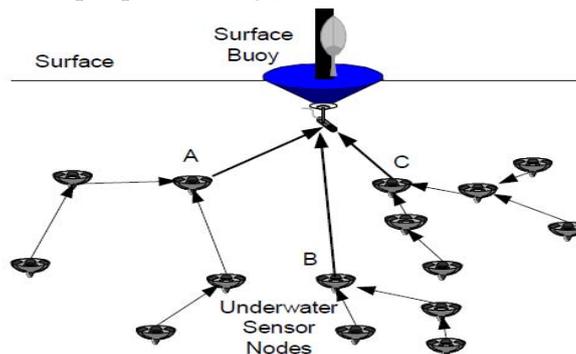


Fig. 2: Network model

5. Simulation Results

From Figure 3, it can be seen that achieves the lowest normalized overheads as multiple RTS are collated before a CTS is transmitted. CDMA based MAC protocol is able to achieve the highest throughput also. This shows the effectiveness of CDMA based MAC in multipath transmission scheme. The delay incurred by CDMA based MAC in multipath transmission scheme is high as all intermediate destination nodes have to wait for at least `RTS_TIMEOUT` before transmitting CTS to the source nodes. We evaluate the performance of the protocol using the metric normalized overhead, which is the no of control packets generated as fraction of no of data packets received.

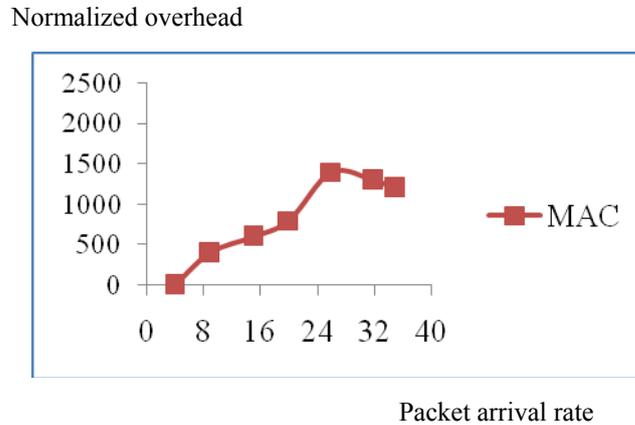


Fig. 3: Normalized overhead vs network size for MAC

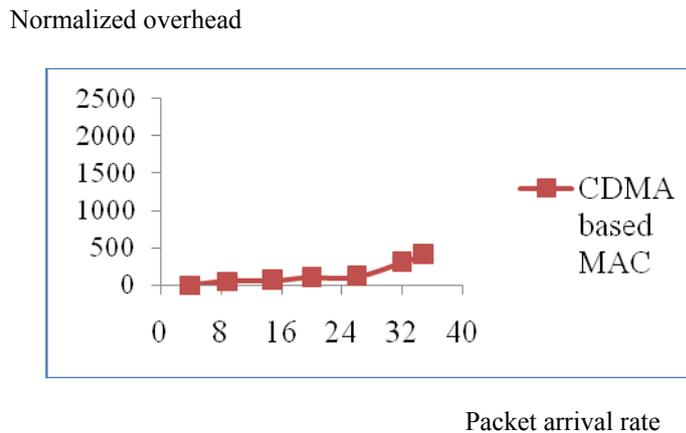


Fig. 4: Normalized overhead vs network size for CDMA based MAC.

6. Conclusion and Future Work

Multipath transmission scheme is suitable for time critical applications in underwater sensor network applications. Power control mechanisms in multipath transmission scheme give better energy efficiency. Integrating multipath communication with CDMA based MAC protocol reduces the network overhead to a great extent. Typical terrestrial MAC protocols are unable to handle long propagation delays in underwater acoustic environments. Existing underwater MAC schemes are generally centralized in nature and therefore not scalable for large sensor networks. Distributed CDMA based MAC protocol utilizes CDMA as the underlying multiple access technique to minimize multipath and Doppler effects which are inherent in underwater physical channels.

We would like to pursue our future work in the following directions:

- Copies of the same packet are sent along multiple paths in multipath transmission scheme. We would like to integrate multipath transmission scheme with coding techniques such as erasure codes to further improve the system performance.

- In underwater sensor network environment, interference and collisions among nodes are not negligible anymore. We would like to investigate a new distributed optimization model that takes interference and collisions among nodes into consideration under the framework of multipath transmission scheme.

7. References

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