Short Paper: Impact Analysis of Different Scheduling and Retransmission Techniques on an Underwater Routing Protocol

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Extended Abstract

Despite many advances in the area of Underwater Wireless Sensor Networks (UWSN) during the last years, still many challenges need to be successfully tackled before large-scale deployment of underwater sensor networks becomes a reality. UWSNs usually employ acoustic channels for communications, which compared with radio-frequency channels, allow much lower bandwidths and have longer propagation delays.

In the past, different methods have been proposed to define how a node must acquire the channel in order to start a transmission. Given the large propagation delays of underwater communication channels, a TDMA-based approach may need big time-guards. On the other hand, the very same large propagation delay increases the occurrence of the hidden terminal problem in a CSMA-based approach.

In this paper, impacts of utilization of different scheduling and retransmission techniques on an underwater routing protocol will be analyzed. This analysis, in which energy consumption, packet delay, number of duplicate packets, and packet loss are considered, will be carried out by means of simulation using the *Network Simulator 3* and a subset of EDETA (Energy-efficient aDaptive hiErarchical and robusT Architecture) routing protocol recently adapted to UWSN.

Categories and Subject Descriptors

C.2 [**Computer-Communication Networks**]: Network Protocols.

General Terms

Algorithms, Measurement, Performance.

1. INTRODUCTION

While Underwater Wireless Sensor Networks (UWSNs) share many characteristics of the Wireless Sensor Networks (WSNs) such as the need for energy-efficient hardware and protocols, specific nature of their deployment area, i.e., water, makes the current protocols developed for WSNs to be unsuitable or very inefficient for UWSNs [17]. The main difference between UWSNs and WSNs stem from the fact that they use different transmission mediums. While in WSNs the communication is done over-the-air using radio-frequency (RF) waves, in UWSNs acoustic signals are used. This is because RF signals are heavily attenuated underwater.

Acoustic waves present different signal attenuations depending on distance and frequency [10] and the signal spreading is also proportional to the distance [13]. Another problem faced by underwater communication comes with the signal propagation, which is 1500 m/s and five orders of magnitude lower than its RF counterpart and is not negligible.

Given this long propagation delay, the original medium access techniques developed for RF networks, such as TDMA or CSMA, might not perform well [2]. The use of a scheduling algorithm to organize the transmissions can, on one hand, avoid collisions, and on the other, reduce or even remove the time-guards, taking advantage of the propagation delay and overlapping transmissions.

In addition, underwater transmission suffers from high noise ratios, which might lead to packet errors and data losses. Forward error correction codes and retransmission techniques can be used to try minimize the packet lost ratio.

In this paper, we aim to analyze impacts of different delay-aware and non-delay-aware scheduling and retransmission techniques when applied under water. Specifically, we analyze their impact on a routing protocol named EDETA (Energy-efficient aDaptive hiErarchical and robusT Architecture), which was recently adapted to UWSNs [4] in terms of energy consumption, packet delay, number of duplicate packets, and packet loss using simulations in *Network Simulator 3* [1].

The remaining of this paper is organized as follows. In Section 2 state of the art on underwater MAC and routing protocols, as well as, scheduling algorithms will be presented. Section 3 provides a brief introduction to EDETA, while Section 4 introduces different scheduling and retransmission techniques used in the experiments. Section 5 de-

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scribes our simulation and obtained results. Finally, in Section 6 conclusions are drawn and our future work is highlighted.

2. RELATED WORK

Underwater acoustic transmission has been heavily studied during the last decade. Recently, significant advances in MAC and routing protocols for underwater sensor networks have been witnessed. Good surveys reviewing the recent advances and challenges in underwater sensor networks can be found in [17, 8].

On the MAC layer, the propagation delay and packet collisions have been the most studied factors. Molins et. al. propose in [7] the Slotted FAMA MAC protocol which aims to provide energy savings reducing the lengths of the RTS/CTS packets by combining them with a TDMA schedule. On the other hand, T-Lohi (Tone-Lohi) [11], uses another approach to reduce the length of the RTS/CTS combining them with CSMA.

There are some proposals that take advantage of the propagation delay and overlap multiple transmissions in order to increase the throughput. Authors in [5] propose ST-MAC, which is a centralize scheduling algorithm that divides the transmissions into multiple timeslots which may lead to sub-optimal results [14]. STUMP-WR [6] is also able of overlapping different transmissions using TDMA slots but scheduling them in a distributed manner.

In [14], van Kleunen et al. introduce a set of scheduling constrains to avoid interferences and propose a centralize scheduling algorithm to take advantage of the propagation delay. Later in [15] they extend this set of scheduling constrains to allow the schedule to be performed in a distributed manner using clusters of nodes.

Different routing protocols have been proposed also to mitigate this effect. Zorzi and Casari study in [19] the effects of the differences between the terrestrial and underwater transmission mediums and the relationship between energy consumption and different radio modes. Furthermore, they design a set of new routing protocols considering these studied factors. Although they make the assumption that each node has information about its position, it is not specified how localization is performed.

There are some approaches that use geographic routing protocols. In the VBF (Vector-Based Forwarding) algorithm [18] a node forwards a packet if the node is close enough to the estimated routing vector. The sender encapsulates into the data packet its position and the receiver position. With this information an intermediate node will forward the packet if it is close enough to the routing path.

QELAR (Q-learning-based Routing) is presented in [12]. It is an adaptive routing protocol based on a machine learning approach. When a node needs to transmit data, it piggybacks some state information. Every time a node receives a packet, even if it is not its destination, it reads the added state information and updates its state and routing function.

Minimum Cost Clustering Protocol (MCCP) is a distributed clustering protocol proposed in [16]. The authors propose a cluster-centric cost-based optimization problem for the cluster formation. Although cluster-heads have the ability to send the data in a multi-hop manner to reach the sink, all nodes are supposed to be able to reach the sink.

3. EDETA

EDETA (Energy-efficient aDaptive hiErarchical and robusT Architecture) is a routing protocol originally proposed for WSNs [3] and recently adapted to UWSNs [4]. It is a hierarchical protocol and nodes arrange themselves in clusters with one of them performing role of the cluster-head (CH). The CHs form a tree structure between themselves in order to send the collected and aggregated data from the other nodes to the sink in a multi-hop manner.

EDETA operation is divided into two phases; (i) the initialization phase and (ii) the normal operation phase. During the initialization phase, clustering is done and cluster-heads are elected. During the normal operation phase, the nodes send their data periodically, at their scheduled times, to their CHs. Finally, cluster-heads send their data to their parents until the data reaches the sink.

An enhanced version of EDETA, called EDETA-e (EDETA-enhanced), also allows the designers of the network to accurately plan and choose which nodes act as CHs. In this variant of the protocol the initialization phase is done only once.

The protocol also defines a schedule mechanism in order to avoid packet collisions during the normal operation phase. The schedule originally proposed for this phase is TDMA, which according to [14] may be inefficient due to the large propagation delays existing in UWSN.

In this work, EDETA-e is used to carry out the performance analysis of different scheduling and retransmission techniques which, in the following sections, are introduced and evaluated in order to analyze their performance when combined with a routing protocol.

4. SCHEDULING AND RETRANSMISSION TECHNIQUES

As previously stated, UWSNs suffer from high propagation delays, which can make the traditional TDMA and CSMA medium access techniques inefficient [2]. Scheduling the transmissions allows to avoid collisions and can reduce the propagation delay, taking advantage of it and overlapping them.

However, it is also necessary to introduce an extra time in the schedule to allow the retransmission of the packets in case a packet error occurs.

To evaluate the impact of different scheduling and retransmission techniques on our underwater routing protocol, we will consider two different scheduling techniques and two different retransmission techniques.

In what follows, we introduce different combinations of the scheduling and retransmission techniques used to replace the original scheduling and retransmission technique of EDETA. The delay-aware schedule has been implemented using the simplified set of schedule constrains proposed by van Kleunen et al. in [15].

TAck. TAck is a TDMA schedule with acknowledgement and data packet loss. A TDMA schedule is used by the nodes to send their data and an ACK is sent back when the data is correctly received. Since this schedule is not delay-aware, the slots have to include the maximum propagation time. Each transmission is scheduled two times to provide a backup slot in case of a data packet error occurs.

TnoAck. TnoAck is a TDMA schedule without acknowledgement. A TDMA schedule is used by the nodes to send their data but no ACK is sent back. Hence, the TDMA slot will last just the time needed for the packet transmission and the signal to propagate to the maximum distance.

DAck. DAck is a delay-aware schedule with acknowledgement and data packet loss. A delay-aware schedule is used by the nodes to send their data and an ACK is sent back when the data is correctly received. Each transmission is scheduled two times to provide a backup slot in case of a data packet error occurs.

DnoAck. DnoAck is a delay-aware schedule without acknowledgement. A delay-aware schedule is used by the nodes to send their data but no ACK is sent back. Each packet is scheduled to arrive at the destination right after the previous one.

DnoAck2. DnoAck2 is a delay-aware schedule without Acknowledgement. A delay-aware schedule is used by the nodes to send their data but no ACK is sent back. As in the previous section, each packet is scheduled to arrive at the destination right after the previous one but, each packet is schedule and transmitted twice.

5. PERFORMANCE EVALUATION

In this section, impacts of the scheduling and retransmission techniques introduced in the previous section are evaluated on EDETA-e in order to compare them with the original TDMA approach in terms of delay, packet loss, energy consumption, and number of duplicate packets.

EDETA-e with the different scheduling and retransmission techniques, was tested in three different deployment areas, i.e., (i) 100×100 meters, (ii) 150×150 meters, and (iii) 200×200 meters. In all of these deployments, 50, 100, and 200 nodes were randomly distributed, which result in 9 different scenarios to test. Each scenario has been simulated several times in order to achieve a confidence interval of $\pm 3\%$ with a confidence level of 95%.

All simulations were seeded using the number 1310572618 and each repetition was done advancing the run number [1].

Leaf nodes start with 150 Joules of energy. The transmission power was set to 0.203 wats, the reception and idle power to 0.024 wats and the sleep power to 3×10^{-6} watts. The transmission range of the nodes was limited to 100 meters adjusting the model transmission power. These values were extracted by A. Sanchez et al. from their low-cost, low-power underwater acoustic modem [9]. The transmission speed was set to 500 bps. This speed could be increased, but we wanted to take into account the speed reduction produced by the use of CDMA spreading codes.

The configuration phase of the EDETA-e protocol was set to last for 18000 seconds and the nodes where configured to send their data periodically every 250 seconds. Each node woke up at its defined time interval and sent one byte with its collected data to its CH. After that, each CH had to aggregate these data and sent it to its parent in the tree structure until the data reached the sink.

5.1 TnoAck vs. DnoAck

In these experiments, the performance of a TDMA schedule and a delay-aware schedule, both of them without acknowledgement, were evaluated.

Given the hierarchical nature of the protocol, one notes that the packet delay is heavily influenced by the network topology and since the transmission range used in the simulations is relatively small (100 meters), the propagation delay is not the dominant factor of the packet delay in these simulations. As it can be seen from Figure 1a, there are almost no significant differences in packet delay between the two alternatives.

Also, as depicted in Figure 1b, energy consumption of the leaf nodes is the same for the two cases since, in both alternatives, the nodes only wake up to send their data and then go back to sleep without waiting for any acknowledgement. On the other hand, Figure 1c shows that CHs consume less energy when they use the delay-aware schedule compared with when they use the TDMA schedule. This difference in energy consumption is produced at the initialization phase where, given the different scheduling algorithms, the initialization phase is slightly different in both alternatives.

5.2 TAck vs DAck

In these experiments, the performance of a TDMA schedule and a delay-aware schedule, both of them with acknowledgement and a scheduled backup transmission are evaluated.

The behavior of duplicate and lost packets is not shown due to page limitations but it behaved as expected. Since there is always a backup transmission scheduled right after the main transmission and the data packet error rate was set to be 10%, the packet lost rate is 1% in every scenario and the duplicate data packets is around 10%.

Focusing on the delays, when acknowledgements and poll messages are introduced, the TDMA slots increase. On the other hand, the delay-aware schedule can optimize the data transmissions and by doing so it can reduce the delays as depicted in Figure 2a.

This reduction in the time spent for communication comes with a reduction on the energy consumption of the CHs. Figure 2c shows the energy consumption of the CHs during the first 100000 seconds of simulation. As it can be seen, the delay-aware schedule consumes less energy than the TDMA schedule.

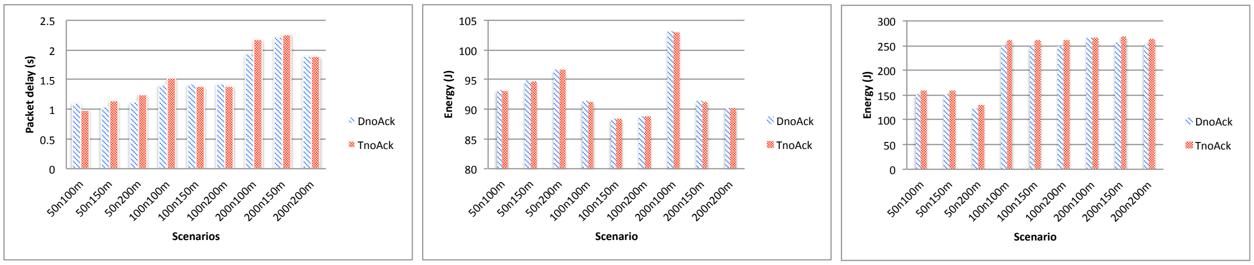
On the other hand, leaf nodes do not get any benefit from the delay-aware scheduling, as they consume the same amount of energy in every scenario as depicted in Figure 2b. This happens because the leaf nodes have to wait for the acknowledgement packet and in both cases they are immediately sent after the data packet arrives.

5.3 DAck vs DnoAck2

In this section, we compare the delay-aware schedule with acknowledgement and the delay-aware schedule with two scheduled transmissions and no acknowledgement (DnoAck2).

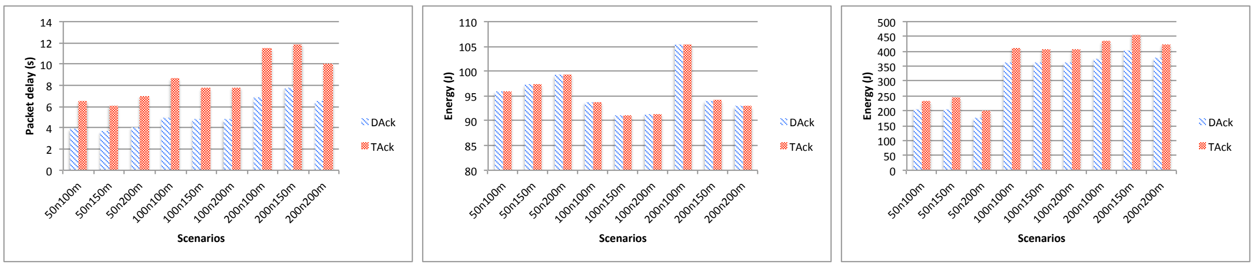
In terms of packet lost, duplicate packets and packet delay, the DnoAck2 alternative behaves as expected. The lost packet ratio is the same as the DAck alternative since in both cases the data will be lost if both scheduled data transmissions fail. However, DnoAck2 has 100% duplicate data since each packet is sent twice. On the other hand, as shown in 3a the delay of the DnoAck2 alternative is the smallest one of the three alternatives.

In terms of energy consumption of the leaf nodes, the



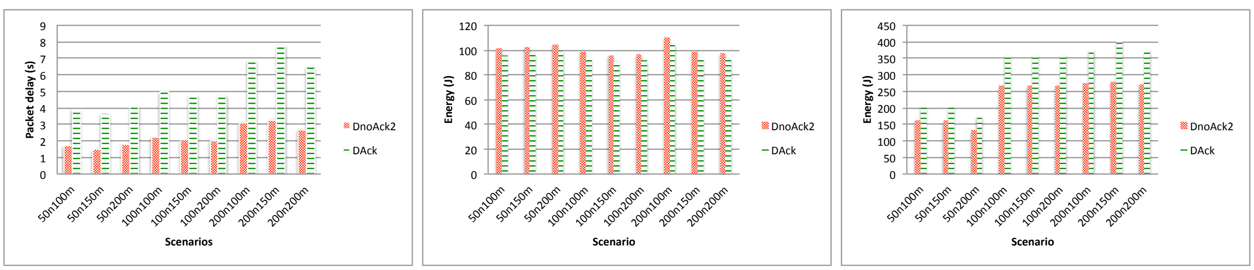
(a) Delay (b) Leaf nodes energy consumption (c) CH nodes energy consumption

Figure 1: TnoAck and DnoAck comparison



(a) Delay (b) Leaf nodes energy consumption (c) CH nodes energy consumption

Figure 2: TAck and DAck comparison.



(a) Delay (b) Leaf nodes energy consumption (c) CH nodes energy consumption

Figure 3: DAck and vs DnoAck2 comparison

DnoAck2 alternative has the biggest overhead since it transmits each packet twice. On the other hand, CH nodes using DnoAck2 have the lowest energy consumption. These nodes also have to transmit their data twice but, this extra energy consumption is compensated by the energy saving given by not sending acknowledgements back which also allows to make the communication faster. Hence, CH nodes can remain in low power state during more time.

6. CONCLUSIONS

In this paper, different scheduling and retransmission techniques applied to a routing protocol have been simulated and their performance in terms of energy consumption, delays, packet lost rate and duplicate packets has been analyzed.

Results have shown that, given the relatively small transmission range of the networks simulated, there is no difference in delay and energy consumption during the normal operation phase of the TnoAck and DnoAck alternatives. However, when the rest of the control packets of the EDETA protocol are introduced (ACK and POLL) the packet delay in the TAck alternative is higher than in the DAck alternative. This difference in the delay also comes with a high energy consumption of the cluster-heads.

The DAck and TAck alternatives also have a retransmission technique based on scheduling a backup transmission right after the primary transmission. Since both of them use the same technique, the lost and duplicate data rate is the same in both alternatives. If the packet error rate can be known a priori or can be estimated, the nodes can dynamically adjust the number of backup transmissions in order to achieve a desired packet lost rate.

Finally, the DnoAck2 alternative offers some interesting results. Since there is no acknowledgement packet sent back, the CHs are able to save energy but, this saved energy is used by the leaf nodes to do the retransmissions. Given the energy consumption of the underwater networks, where the transmission state is more expensive than the reception state, the transmission overhead has to be carefully planed for energy-aware protocols.

Future work includes impact analysis of the studied scheduling and retransmission techniques on different network topologies such as underwater long linear arrays as well as drafting a guideline for the optimal use of re-transmission and TDMA, CSMA and delay-aware scheduling techniques under different circumstances.

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