An Energy-Efficient MAC Protocol for Underwater Sensor Networks

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I. INTRODUCTION

Underwater sensor networks have received growing interests recently [7], [5], [4], [1]. Compared with traditional techniques used in underwater activities such as scientific exploration and commercial exploitation, underwater sensor networks empower people to monitor or detect phenomena more accurately and timely in extended areas.

The medium access control (MAC) protocol is very important to the final performance of underwater sensor networks. Different applications have different requirements on MAC protocols. In this paper, we aim to design a MAC protocol for the long term applications such as environment monitoring. These applications are not sensitive to the end-to-end delay and generate sporadic traffic unevenly distributed spatially and temporally. We focus on the dense sensor networks where neighboring nodes are located a few hundred meters apart and the bit rate of the underwater acoustic modem is around 10 kbps. The most important goal of MAC for such underwater sensor networks is to resolve data packet collision efficiently in terms of energy consumption.

However, the characteristics of underwater sensor networks and the requirement for energy efficiency make the existing MAC protocols proposed for radio sensor networks unsuitable for underwater sensor networks. In underwater sensor networks, acoustic channel is used as the communication method. The propagation speed of sound in water is about 1500 m/s, which is 5 order of magnitude lower than that of radio. The low propagation speed results in a high propagation delay even for communication between two neighbors. The available bandwidth for an acoustic networks is typically less than 15 KHz, which is extremely narrow compared with radio networks. The low propagation speed makes the widely used collision avoidance method namely RTS/CTS, unfeasible in underwater sensor networks. As shown in[2], in order to completely avoid data packets collision, two conditions have to be satisfied: 1)The duration of RTS should be greater than the maximum propagation delay, and 2) The duration of CTS should be greater than that of RTS plus twice the maximum propagation delay plus the hardware transmit-to-receive transmission time. It is easily to satisfy the two conditions in terrestrial sensor networks, however, it is too expensive to do so in underwater sensor networks where the maximum propagation delay might be greater than 50 ms. The size of the control packets would be unacceptably large. Furthermore, the problem is made more complicated by the requirement for energy efficiency. In order to save energy, the sensor nodes have to sleep and wake periodically.

In this paper, we address this problem under the energy constraint. We propose an energy efficient MAC protocol, reservation-based MAC protocol, R-MAC for underwater sensor networks. In R-MAC, we schedule the transmission of control packets and data packets on both the sender and receiver to avoid data packet collision completely. Moreover, R-MAC supports fair sharing of the channel among the competing senders. Additionally, we adopt a new ARQ technique, block-based acknowledgment in R-MAC to improve the channel utilization.

II. PROTOCOL DESCRIPTION AND PRELIMINARY RESULTS

A. R-MAC Protocol

The major goal of R-MAC is to avoid data packet collisions without increasing energy consumption.

Like the MAC protocols for terrestrial sensor networks [8], [6], R-MAC also adopts periodic listen/sleep to reduce the energy waste on idle state and overhearing. However, different from these protocols, each node in R-MAC randomly selects its own schedule. The random schedule on each node reduces the energy waste on overhearing, meanwhile, looses the synchronization requirement. The duration for listen is the minimal amount time needed for possible reservations. If there is no traffic, each node spends energy on idle state as little as possible. Each node in R-MAC has the same listen and sleep durations.

The message exchange in R-MAC is REV/ACK-REV/DATA/ACK-DATA. When a node has data packets to send, the node first schedules to delivery the reservation, denoted as REV during the listen window of the intended receiver. Upon receiving the confirmation from the receiver, denoted as ACK-REV, all nodes other than the intended sender schedule their silence time to avoid interrupting the subsequent transmission, the sender then schedules its transmission of data, denoted as DATA accordingly. The data in R-MAC are transmitted in a burst. A node queues its data for the same receiver until it captures the channel, then injects all the queued data. In order to reduce the control packet overhead and improve the channel utilization, the receiver acknowledges the burst instead of the individual packet by replying the sender with an acknowledgment packet, denoted as ACK-DATA.

The nodes in R-MAC synchronize each other to avoid data packet collisions. R-MAC needs to prepare its nodes for the synchronization required in periodic listen/sleep. R-MAC has three phases, namely, latency detection phase, period announcement phase and periodic operation phase. A node in the latency detection phase detects the propagation latency to all its neighbors. In period announcement phase, each node randomly selects its own listen/sleep schedule and broadcasts this schedule. In the periodic operation phase, the nodes in R-MAC transmit data packets based on the measurements in the first two phases.

B. Preliminary Results

We have finished some theoretical analysis to show that R-MAC is data packet collision-free. In addition, we have conducted some simulations to evaluate the performance of R-MAC by comparing the performance of R-MAC with T-MAC, a protocol proposed for radio sensor networks[6].

We set the control packet size to 5 B and the data packet size to 60 B. The duration of one period is set 1 second and the listen window is 100 ms. The bit rate is 10 kbps. The data sending follows Poisson process. We assume the encoding-efficiency in physical layer is 1 and no overhead caused in physical layer. The maximum transmission range is 90 meters. The transmission range is the same as the interference range. The maximum number of data packets allowed in a burst is 3 in R-MAC. The simulation time for each trial is set 4000 seconds. We set the energy consumption parameters based on the underwater acoustic modem, UMW1000, from LinkQuest [3]. The power consumption on transmission mode is 2 Watts, power consumption on receive mode is 0.75 Watts, and the power consumption on the sleep state is 8 mW. We run 100 times with different random seeds.

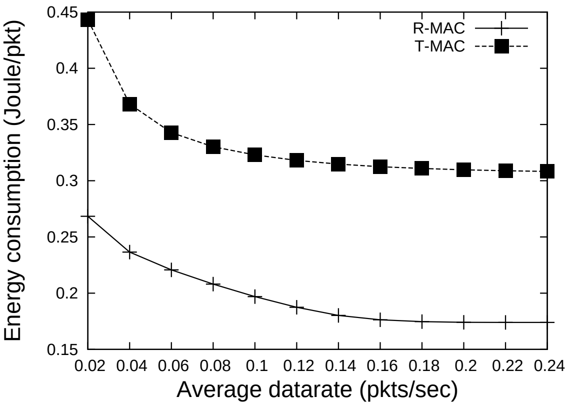

Fig. 1. The energy consumption per data packet in R-MAC and T-MAC

We get the energy consumption to successfully send one data packet in R-MAC and T-MAC as shown in Fig. 1. Fig. 1 shows that R-MAC is energy efficient than the modified T-MAC under variable data traffic. This set of simulations show that we can not apply the idea of T-MAC directly in underwater sensor networks, which is not energy efficient.

III. CONCLUSIONS AND FUTURE WORK

The long propagating delay in underwater sensor networks makes the existing energy efficient methods for terrestrial sensor networks undesirable in underwater sensor networks.

We propose an energy efficient MAC protocol, R-MAC for underwater sensor networks. R-MAC schedules the transmission of control and data packets to avoid data packet collisions. R-MAC resolves the data packet collision effectively and efficienctly. Additionally, R-MAC adopts new ARQ technique, namely block-based acknowledgment reduces the control packet overhead further and improves the channel utilization. As future work, we would like to make R-MAC robust in the error-prone communication channel.

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