Improved Performance of Enhanced Receiver Initiated Packet Train (E-RIPT) for Underwater Acoustic Networks

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Abstract

This paper proposes a Modified Enhanced Receiver-Initiated Packet Train (ME-RIPT) Media Access Control (MAC) protocol for an underwater acoustic network. It is designed specifically for underwater acoustic sensor networks, which is characterized by low data rate and long propagation delay. We design a new control signaling which alleviates the exposed problem. The simulation result shows improvement in throughput, delay, and fairness compared to its predecessors, RIPT and E-RIPT for various environment settings.

Keywords: Underwater acoustic communication; E-RIPT, Access protocols; Multi access communication.

1. Introduction

In past few decades, many underwater applications help enable activities on and in the ocean. Underwater sensors networks help detect polluting chemical and biological substances such as oil or insecticide. They can also monitor oceanic wind and current to improve weather forecast capability. Seismic sensors can also provide tsunami warning to coastal areas. All these activities are possible due to communications infrastructure called 'Underwater Acoustic Network' (UAN).

Unique characteristics of acoustic channels make it difficult to directly apply radio communication theory for terrestrial networks [1]. Radio wave typically travels through conductive salty water by a carrier with low frequency (e.g. 30–300 MHz). It also suffers greatly due to scattering under underwater harsh environment. Acoustic wave travels at very low speed, typically approximately 1500 m/s or equivalently large propagation delay of 0.67 s/km. These physical properties limit bandwidth of a typical acoustic channel, resulting in very small data rate. In general, a single-hop data rate in UAN is no greater than 40 km-bit per second [3].

At Medium Access Control (MAC) layer, the challenges are due to the above physical properties as well as limited energy. Traditional MAC protocols like CSMA/CA determine whether the channel is busy by active listening [2]. These protocols work well under terrestrial networks, where, with small propagation delay, it can be assumed that a receiver overhears the conversation as soon as a transmitter starts transmitting. In a UAN with long propagation delay, a receiver needs to sense channel idle for longer than propagation time in order to be sure that the channel is free. This imposes great overhead on traditional MAC protocols. For a UAN, MAC protocols need to be devised to address this problem.

This paper proposes a UAN MAC protocol called Modified Enhanced Receiver-Initiated Packet Train (ME-RIPT). Comparing to its predecessor E-RIPT proposed in [5], ME-RIPT improves performance in terms of throughput, delay, and fairness.

2. Related work

Specifically for UAN, in [6], MACA-U used a three-way handshake RTS/CTS/DATA to avoid data collision. Long propagation delay and single packet transmission per round cause channel under-utilization for MACA-U. RIPT in [7] utilizes receiver-initiated 4-way handshake and allows transmission of multiple data packets per round—called 'Packet Train'. Compared to MACA-U, the handshake mechanism alleviates the hidden node problem, while packet train improves channel utilization. However, RIPT requires the knowledge of propagation delay of all nodes in the network. This is fairly difficult to achieve in practice. RIPT also have a problem of prediction the demand to transmit data from other nodes. When the prediction is inaccurate, the schedule is inefficient, and some time slots could be left unoccupied. BiC-MAC in [8] is

TABLE 1: Notations of packet types and variables

Packet type/Variable	Implication
REV	Ready to Receive a Packet
REV-ACK	Acknowledge to REV
NTF1 and NTF2	Notify other nodes to be SILENT
ORDER	Announcement of transmission order
$D_{\max}$	One hop propagation delay
S_{all}	Number of slots to receive REV-ACK
$M_{\max}$	Maximum number of packets a node can transmit per round
T_{avg}	Average time to switch node state from IDLE to BEACON
$t_{\text{Firstslot}}$	Time to start receiving REV-ACK
t_{busy}	Time to broadcast ORDER

another handshaking protocol for bidirectional data transmission. It works well only when the transmission time of each packet is shorter than the propagation delay between nodes.

MACA-APT [9] allows the sender to send packets to multiple receivers in one round. Each packet also contains timing information for letting other nodes sleep until their turn comes. Due to timing information, exposed nodes can over-slept and cause channel under-utilization.

E-RIPT [5] uses a receiver-initiated handshake under slotted environment. A handshake message contains timing information. Nodes receiving this information will refrain from data transmission until the time specified in the handshake message. While alleviating collision, the handshake introduces an exposed node problem.

3. Modify Enhanced Receiver-Initiated Packet Train

3.1 Assumption and Notations

We consider a static UAN where every node does not move. Each node has the same transmission range and knows propagation delay of all neighboring nodes. Also, each node generates packets according to Poisson distribution. The notation used in this paper is shown in Table I.

TABLE 2: Node State

State	Implication
IDLE	Ready to become a receiver or a sender
BEACON	Ready to receive packets
SLAVE	Allowed to send packets
SILENT	Refrain from transmitting packets

3.2 ME-RIPT Protocol

The operation of ME-RIPT consists of two main parts: Handshake and data reception (see Fig. 1). During a handshake period, and informs all sending nodes of receiving schedule. In the data reception period, conforming to the schedule, all sending nodes transmit with no data collision.

In ME-RIPT, we define 4 node states as shown in Table II. Apart from IDLE state, a node sets timer as soon as its enters each states. When the timer expires (i.e., timeout), the node switches its state to IDLE. When a node wants to receive data, it waits for an exponentially random amount of time with an average T_{avg} and switches its state to BEACON.

A handshake begins when a BEACON node broadcasts a REV packet. A REV packet lets other nodes know that the node is ready to receive packets. A node receiving a REV packet switches its status to SLAVE and broadcast a notification message NTF1. If the node, overhearing an NTF1, does not have any packets to transmit to the receiving node, it will be SILENT until the handshake is complete. Otherwise, it will acknowledge with a REV-ACK packet, telling the number of packets destined for the receiving node.

Receiving a REV-ACK packet, the receiving node broadcasts an ORDER packet to inform neighboring

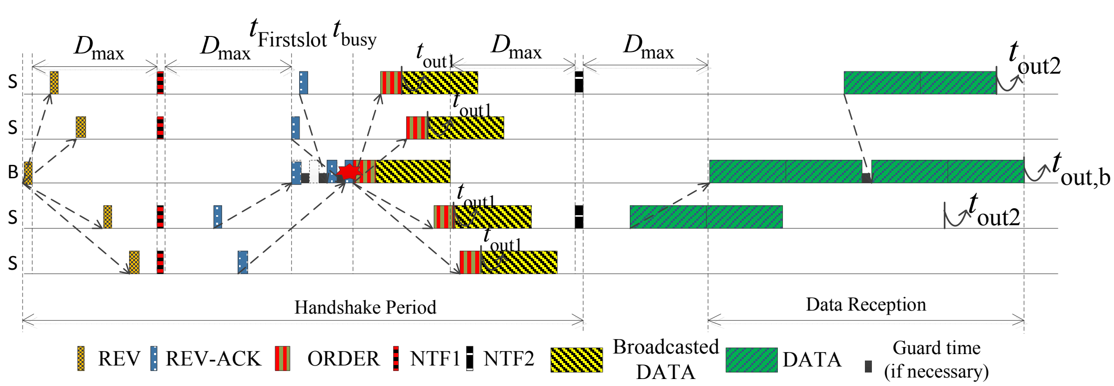

Fig.1 Diagram of ME-RIPT

TABLE 3: Simulation network topology

Grid spacing	700 m
Communication range	1225 m
Propagation speed	1500 m/s
Transmission rate	2400 b/s
Traffic model	Poisson distribute
MACA-U packet size	
RTS	24 bits
CTS	24 bits
RIPT packet size	
RTR	40 bits
SIZE	56 bits
ORDER	184 bits
E-RIPT, and ME-RIPT packet size	
REV	48 bits
REV-ACK	72 bits
ORDER	184 bits
NTF1, NTF2	56 bits
DATA	
Packet size	2400 bits
Header size	80 bits

nodes of their transmission schedule. Upon receiving an ORDER packet, a sending node broadcasts an NTF2 packet to inform nodes in the second hop to/from the receiving node to refrain from transmitting packets until packet transmission in the current round is complete. After finishing transmission, each sending node waits for timer to expire and switch its status to IDLE.

Note that while waiting to switch the state from IDLE to BEACON, if the node receives a REV or NTF1/NTF2, it will cancel the wait and switch its state to SLAVE or SILENT, respectively.

4. Simulation Setup and Results

4.1 Simulation Setup

This section presents a part of experiments on ME-RIPT. As shown in Fig. 2 (a), we assume a grid topology with 196 nodes. Each node can drift away from its position by 10% on both in x and y directions. We collect simulation results only from the middle 36 nodes to avoid the boundary effects. We run simulation for 300,000 seconds, and discard the result from the first 60,000 seconds to avoid transient effect. We use two-hop routing as shown in Fig. 2 (b). The central (i.e., receiving) node broadcasts to every neighboring node while the neighboring nodes send packets to only two nodes in the second hop. Other basic simulation parameters are shown in Table 3. Unless otherwise specified, we use S_{all} = 8 slots, T_{avg} = 10 s, and M_{max} = 20 and 50 packets.

We measure normalized throughput, packet delivery delay, and fairness to show performance of ME-RIPT. Normalized throughput λ is defined in (1) below. It is

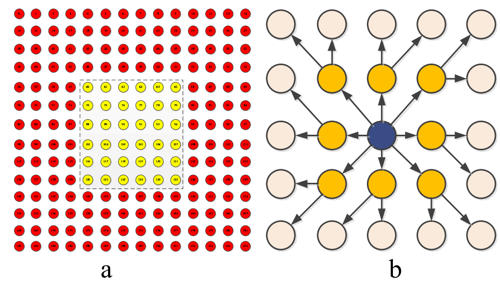

Fig.2. The multi-hop network topology used in our simulation and routing of each node.

the average number of packets successfully normalized by data rate in packets per seconds.

$$\lambda = \frac{1}{36}\left[\frac{\text{No. of Packets Received/Simulation Time}}{\text{Data Rate/DATA Packet length}}\right] \qquad (1)$$

Packet delivery delay is measured from the time a packet is generated to the moment the packet reaches the receiving node. If the packet is lost, the delay will not be accounted for. Finally, we measure fairness in packet transmission opportunities. We measure the number of packet transmitted by each node, and compute the standard deviation. High standard deviation indicates more scattering in the number of packets transmitted by each node and therefore worse fairness performance.

4.2 Simulation Results

Fig.3 shows normalized throughput of ME-RIPT, E-RIPT, RIPT and MACA-U MAC protocols. MACA-U has lowest normalized throughput since each node can send only one packet per round. The result of ME-RIPT in terms of normalized throughput outperforms RIPT. Comparing to RIPT, ME-RIPT notifies right nodes of right timeout. During the first half of the handshake (REV/REV-ACK), NTF1 tells neighboring nodes to be SILENT until the handshake is over. On the second half, NTF2 orders nodes which could interfere with data transmission to be SILENT until the transmission is over. Nodes within the range of REV but does not interfere with transmission can still transmit packets to other nodes. Also, in ME-RIPT, each node indicates the number of packets to be transmitted. With this exact knowledge, the receiver makes more accurate transmission schedule, and normalized throughput improves as a result.

Fig.4 shows the delay performance of selected MAC protocol. At the very light load (less than 1%), MACA-U has near zero delay. It is the lowest among all protocols. This is because of its lower overhead in three-way handshake, and the nature of sender-initiate protocol. With MACA-U, each node initiates

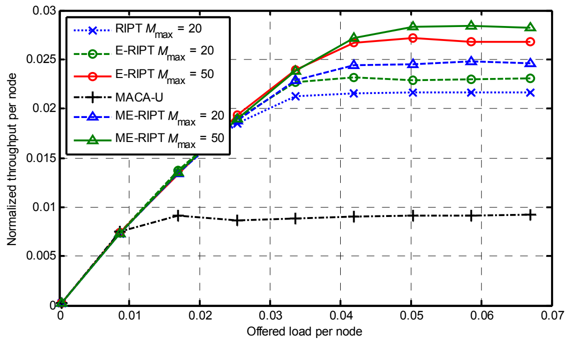

Fig.3. Comparing the normalized throughput of ME-RIPT, E-RIPT, RIPT, and MACA-U.

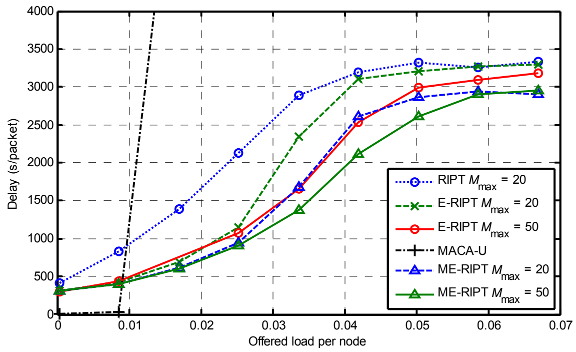

Fig.4. Comparing the packet delivery delay of ME-RIPT, E-RIPT, RIPT, and MACA-U.

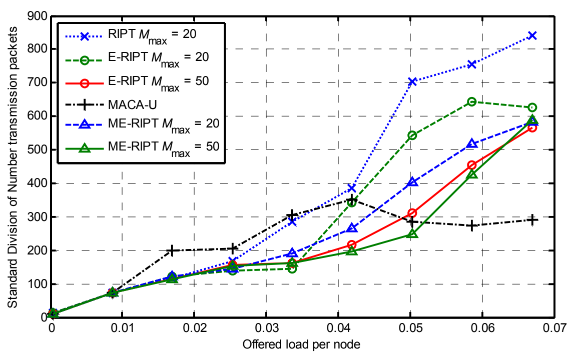

Fig.5. Comparing the standard division of DATA packet transmission from each node of ME-RIPT, E-RIPT, RIPT, and MACA-U.

transmission only when it has data to transmit. It does not wastefully pull data from nodes which has no data to transmit. At light traffic load, MACA-U outperforms all receiver-initiated protocols. As traffic load increases, MACA-U suffers from packets collision. MACA-U also limits transmission to one packet per round, hence limiting normalized throughput for high load.

Among all receiver-initiated protocols, at high load, RIPT has the highest packet delivery delay. E-RIPT outperforms RIPT due to its efficient channel reservation protocol. ME-RIPT performs even better, since it solves an exposed node problem caused by the reservation protocol.

Fig. 5 shows the standard deviation of transmitted packets for all MAC protocols under consideration. MACA-U does not provide good fairness for light traffic load. But, the fairness is better for high traffic load. Here, MACA-U allows transmission of one packet only. The difference in the number of transmitted packets per round is limited to one. This difference is greater in case of other protocols which allow transmission of more than one packet. At high load, MACA-U outperforms all other protocols.

Among receiver initiated protocols, ME-RIPT has the best fairness performance. This is because ME-RIPT alleviates the exposed node problems, giving chance for node to transmit more packets. Also, increasing $M_{\max}$ improves fairness because the receivers have more choice for resource allocation.

5. Conclusion

ME-RIPT is a receiver-initiated MAC protocol for an underwater acoustic network. It alleviates exposed node problems that its predecessors RIPT and E-RIPT experience. The simulation results show the improvement in throughput, delay, and fairness. Interestingly, increasing maximum of packets that a node can transmit per round increases both throughput and fairness.

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