RMAC-M: Extending the R-MAC Protocol for an Energy Efficient, Delay Tolerant Underwater Acoustic Sensor Network application with a mobile data mule node

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Abstract:

One of the major applications of underwater acoustic sensor networks (UWASN) is ocean environment monitoring. Employing data mules is an energy efficient way of data collection from the underwater sensor nodes in such a network. A data mule node such as an autonomous underwater vehicle (AUV) periodically visits the stationary nodes to download data. By conserving the power required for data transmission over long distances to a remote data sink, this approach extends the network life time. In this paper we propose a new MAC protocol to support a single mobile data mule node to collect the data sensed by the sensor nodes in periodic runs through the network. In this approach, the nodes need to perform only short distance, single hop transmission to the data mule. The protocol design discussed in this paper is motivated to support such an application.

The proposed protocol is a hybrid protocol, which employs a combination of schedule based access among the stationary nodes along with handshake based access to support mobile data mules. The new protocol, RMAC-M is developed as an extension to the energy efficient MAC protocol R-MAC by extending the slot time of R-MAC to include a contention part for a hand shake based data transfer. The mobile node makes use of a beacon to signal its presence to all the nearby nodes, which can then hand-shake with the mobile node for data transfer. Simulation results show that the new protocol provides efficient support for a mobile data mule node while preserving the advantages of R-MAC such as energy efficiency and fairness.

Keywords: MAC Protocol, Underwater Acoustic Sensor Networks, Data Mule, Energy Efficiency, R-MAC

1. Introduction

An underwater sensor network is capable of monitoring the vast ocean environment, which is otherwise a difficult and costly exercise by other traditional means such as survey vessels and data buoys. Since the radio waves used in terrestrial sensor networks have very high attenuation underwater, acoustic waves are used for communication in underwater sensor networks. The unique characteristics of the underwater acoustic channel [1] like high

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propagation delay, high and frequency dependent attenuation, low bandwidth and high error rates, bring many challenges to the design of networking protocols for UWASNs.

Since underwater sensor nodes are powered by batteries which cannot be recharged due to the unavailability of solar power, energy efficiency for extending the network life time is an important consideration in protocol design. Moreover, the deployment of sensor nodes in underwater sensor networks is generally sparser than in terrestrial sensor networks. Therefore, the readings are often not spatially correlated and data inputs from each and every node thus assume significance. This calls for fairness among the nodes. Therefore node fairness and energy efficiency are the considerations in the design of protocols for data collection.

Several approaches for data collection are explained in the literature.

1. The traditional approach [2] is to deploy underwater sensors that record data during the monitoring mission, and then recover the instruments after the monitoring mission. In this approach, real time monitoring is not possible. Interaction between the control station and sensor nodes is also not possible.

2. Another approach is connecting the sensor nodes by means of wireless links to a sink node which collects data and transmits to on shore station. Here two strategies can be adopted. Single hopping, where the sensor nodes communicate directly to the sink node and multi hopping, where the data is relayed to the sink [3].

3. Instead of transmitting to a far away sink node (which is highly energy consuming), if the sink node (data mule) is made mobile to travel towards the sensor, the network life time can be extended [4]. This calls for appropriate networking protocols to support node mobility.

Several approaches/protocols for data muling in terrestrial sensor networks with mobile nodes have been developed [5] [6]. Data muling using mobile nodes in underwater sensor networks is an emerging research area.

In this paper, we propose a MAC protocol which is aimed for underwater sensor networks deployed for long term, delay tolerant data muling applications. The new protocol, (RMAC-M), is developed as an extension of the existing reservation based protocol (R-MAC proposed by Xie et al. [7]) to provide support for the mobile data muling node.

The remainder of the paper is organized as follows. Section 2 discusses the network architecture. Section 3 gives an overview of the energy efficient MAC protocol R-MAC. Section 4 analyses the impact of node mobility on R-MAC and also describes the design of the new protocol RMAC-M. Section 5 presents the performance evaluation of RMAC-M. Section 6 summarizes the results and concludes the paper.

2. Network Architecture

The basic elements of the UWASN for our target application are the stationary nodes which are deployed and anchored to the sea bottom. Stationary nodes act as the backbone of the network. A mobile data mule such as an AUV communicates with the stationary nodes for control/data exchange. To simplify the task of the data mule in interacting with a large number of stationary nodes for data transfer, there are gateway nodes which collect data from the adjacent stationary sensor nodes which form a cluster. The mobile data mule interacts with the gateway nodes for downloading the data collected by it from the cluster nodes. When the data is successfully delivered to the recipient gateway node or the data mule, it is deleted from the local memory of the sender nodes. Example network architecture is shown in Figure 1.

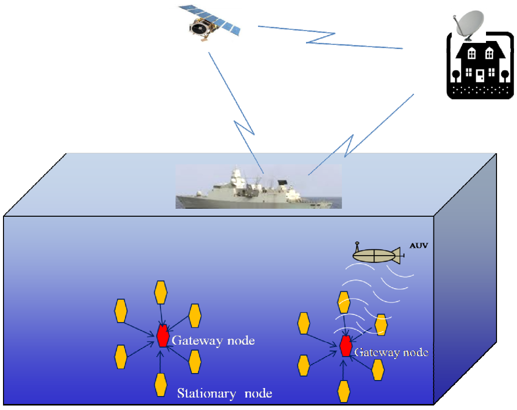

Figure 1: Network Architecture

In this work, we have made an attempt to incorporate support for node mobility into the well known MAC protocol R-MAC, which is a schedule based protocol originally designed for networks with stationary nodes with energy efficiency as the primary goal. Our objective was to provide support for a mobile node in the modified protocol while simultaneously preserving the energy efficiency and fairness of the original R-MAC protocol.

3. Overview of R-MAC

R-MAC protocol is designed for long term monitoring applications with energy efficiency and node fairness as primary design goals. R-MAC schedules all data and control packet transmissions and thus avoids data packet collisions. R-MAC operates in three phases.

3.1 Phase1: Latency Detection

Each node randomly selects a time to broadcast a control packet, called Neighbor Discovery packet, denoted as ND. Upon receiving NDs from its neighbors, a node records the arrival times of these NDs, then randomly selects a time to transmit an acknowledgment packet, denoted as ACK-ND, which has the same packet size as ND, for each of the NDs it receives. In each ACK-ND, the node specifies the duration from the arrival time of the ND packet to the transmission time of this ACK-ND packet, I_2. After receiving an ACK-ND, a node computes the interval from the time that the corresponding ND packet is transmitted to the arrival time of the ACK-ND, I_1. Then the propagation latency, L, between the two nodes can be calculated as $L = (I_1-I_2)/2$.

3.2 Phase2: Period Announcement

In this phase, each node randomly selects its own start time of the listen/sleep periodic operations (i.e., the third phase) and broadcasts this schedule. After receiving broadcast packets, each node converts the received times (schedules) to its own time (schedule).

3.3 Phase3: Periodic Operation

In this phase, nodes wake up and sleep periodically. We call one listen/sleep cycle as one period. In R-MAC, nodes communicate through REV/ACK-REV/DATA/ACK-DATA message exchange, where REV denotes the reservation packet, ACK-REV is the acknowledgment packet for REV, and ACK-DATA is the acknowledgment packet for data DATA. All the control packets in R-MAC, namely REV, ACK-REV and ACK-DATA have the same size, which is much smaller than that of data packets. When a node has data to send, it first sends a REV to reserve a time slot at the receiver. If the receiver is ready for data reception, it will notify all its neighbors about the reserved time slot by ACK-REVs. Upon receiving ACK-REVs, all the nodes other than the sender keep silent in their corresponding time slots, and the sender can send data at the reserved time slot.

4. RMAC-M Protocol

4.1. Impact of Node Mobility on R-MAC

In R-MAC, the scheduling at the sender and receiver is determined based on the propagation delay. Since the data mule node is mobile, the propagation delay between it and the other nodes varies with time. Therefore, frequent estimation of the propagation delays becomes necessary for proper scheduling. Running phase 1 and 2 frequently reduces the efficiency of the protocol in terms of throughput and energy. Therefore, a different approach is called for to extend the R-MAC protocol to address the mobility of the data mule.

4.2. RMAC-M Protocol Description

In the network architecture of interest to us (section 2), the stationary nodes communicate with each other efficiently via the schedule based R-MAC protocol. To accommodate the mobile mule node, in RMAC-M, the stationary nodes leave slots empty in their wakeup periods reserved for possible usage by a passing mobile node. Total wakeup period is divided for schedule based access as well as handshaking based access as in M-LMAC for terrestrial networks [8]. But unlike M-LMAC, the mobile data mule node initiates communication in RMAC-M. The protocol inherently provides a two way data transfer mechanism between the mobile node and a gateway node as shown in Figure 2 and explained below. This can be made use of for sending commands to the gateway nodes.

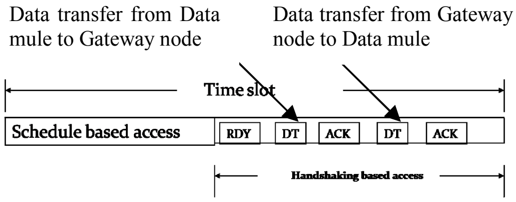

Figure 2: Extended time slot in RMAC-M

Here we assume that only one designated node from each cluster of nodes called the gateway node collects data from all other stationary nodes in the cluster (using R-MAC). These nodes then communicate with the data mule to transfer the cluster data to it. The stationary nodes put their transceivers in listen mode during the contention part of all time slots. The mobile node (AUV) advertises its presence by sending a unique beacon signal for the duration of two time slots. Upon receiving the beacon signal, the gateway node can make use of the contention part of it's timeslot to interact with the mobile node. The gateway node first sends a RDY message. Upon receiving the RDY message, the mobile node transmits data DT and all other nodes stop transmission. The gateway node then acknowledges the data reception with ACK message. ACK message contains a flag bit to indicate whether a data transmission follows. Finally the mobile node acknowledges the DT from the gateway node.

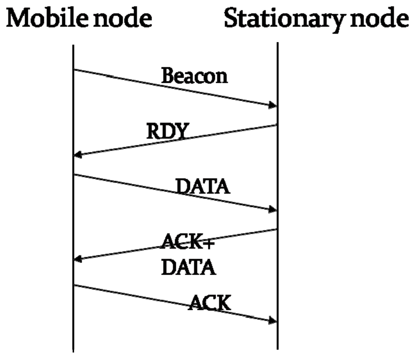

Figure 3: Handshake between mobile node and gateway node.

4.3. Reconfiguration Phase

The communication between the AUV and the stationary node can be used to introduce an additional phase in the protocol called the reconfiguration phase which can be initiated by the AUV. This phase can be utilized for achieving many network wide reconfiguring functions. Some of the possible functions in this phase are:

1. Scheduling of newly added nodes can be done in the reconfiguration phase.
2. Schedule changes of nodes can be done during this phase.

3. Selection of sensors (Nodes equipped with different sensors such as temperature sensor, acoustic sensors, magnetic sensors etc.,) based on commands from the master node (surface station/mobile AUV) can also be done during the reconfiguration phase.
4. Sampling intervals can be changed in the reconfiguration phase.
5. In some applications like oil field monitoring, continuous sensing is not required. In such situations, a command can be given from surface station for putting all nodes in the inactive mode to increase the lifetime of the network.
6. The problem of different nodes waking up at different times due to clock drifts can be avoided by making use of the reconfiguration phase to resynchronize.

5. Simulation Results and Analysis

Simulations were carried out to compare the performance of R-MAC and RMAC-M in the presence of a mobile node. For the simulations, we have used Aqua-Sim [9], an NS2 based simulator for underwater sensor networks. The simulation scenario consists of a network with seven stationary nodes (which is a typical number for a cluster in a sparse UWASN) and a mobile data mule node as shown in Figure 4. Node 0 is designated as the gateway node. The stationary nodes remain deployed and they communicate through basic R-MAC protocol with each other and with the gateway node. When the AUV approaches and announces its presence through a beacon signal, the nodes make use of the contention part of RMAC-M protocol for communication with it. The mule node is made to move at different speeds along different random paths. The mule node follows the random way point mobility model. One sample path is shown in dotted lines.

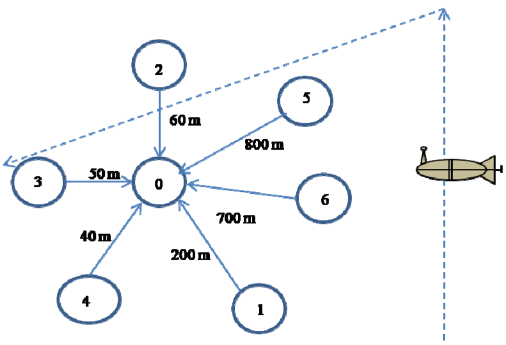

Figure 4: Simulation Scenario

The performance of RMAC-M is independent of the path of the mobile node as long as it is in the transmission range of the sender. The metrics used to evaluate the performance of RMAC-M are delivery ratio of packets (for different speeds and network size), total energy consumption and cumulative delays.

The delivery ratio of packets sent by the mobile node at various speeds of propulsion is shown in Figure 5.

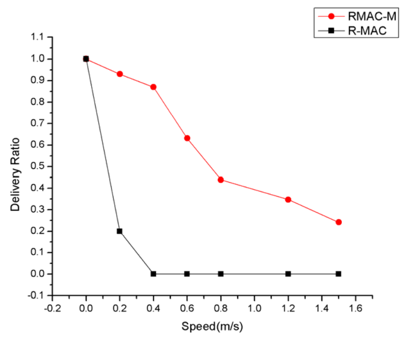

Figure 5: Delivery ratio at different speeds of mobile node.

It is clear from the simulation results that R-MAC has a very low delivery ratio even at low speeds of mobility of the mobile node;

i.e. performance of R-MAC deteriorates rapidly with the speed of mobile nodes. For RMAC-M it can be seen that the delivery ratio is much higher than R-MAC and deteriorates at a much slower rate with the increasing speed of the mobile node.

The delivery ratio is obtained through simulation for different network sizes. It is found that delivery ratio of mobile node is not much dependent on network size (Figure 6).

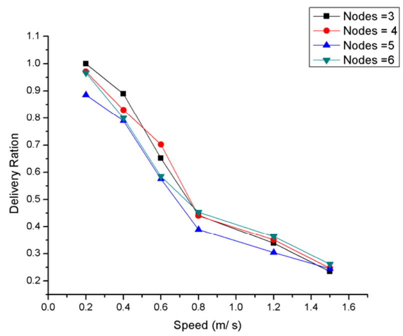

Figure 6: Delivery ratio for different network sizes.

In order to estimate the overhead due to RMAC-M we have computed the total energy consumption of the network consisting of only stationary nodes for R-MAC and RMAC-M for different data rates. It is found that the energy overhead due to extending the wakeup period is negligible (Figure 7).

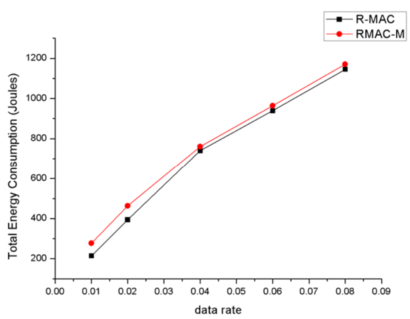

Figure 7: Total energy consumption vs. data rate

The total delivery ratio of the stationary network is measured for R-MAC and RMAC-M and plotted in Figure 8. R-MAC and RMAC-M performs equally well for network with only stationary nodes.

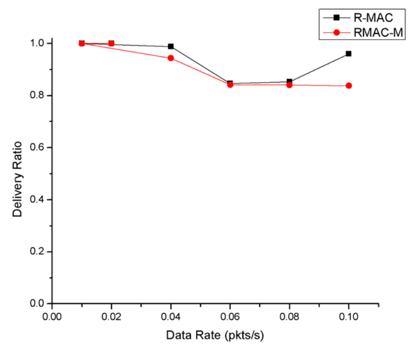

Figure 8: Delivery ratio of network vs. data rate

The cumulative delay at the sink node is computed for the two protocols. It is observed that cumulative delay of RMAC-M is higher than R-MAC (Figure 9) because of the extended time slot in RMAC-M.

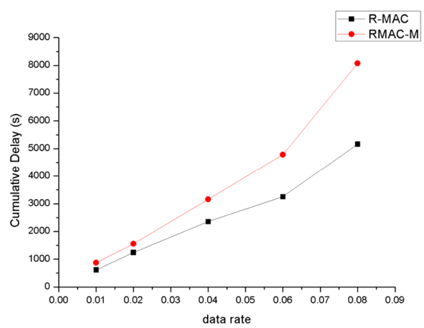

Figure 9: Cumulative delay vs. data rate

6. Conclusion

In this paper we have described a new protocol RMAC-M targeted for UWASNs employing a mobile data mule node for data collection from stationary sensor nodes. It leverages the energy efficiency and fairness of the R-MAC protocol while addressing its deficiency in handling node mobility. It is energy efficient in both stationary networks as well as in the presence of a mobile data mule node.

RMAC-M achieves very high packet delivery ratios compared to R-MAC in scenarios involving mobile nodes. The energy overheads due to extending the wakeup periods of RMAC-M are negligible. As expected, the cumulative delays in RMAC-M are marginally higher than R-MAC.

We intend to analyze the effect of multiple mobile nodes on this protocol in our future work. However, we feel that support for even a single mobile node will be very useful for many UWASN applications involving a mobile node as a data mule and supervisory control.

References

[1]. Dario Pompilli, Rutgers, Ian F. Akyildiz. Overview of Networking Protocols for Underwater Wireless Communications. IEEE Communications Magazine, January 2009.

[2]. F.Akylidiz, D.Pompilli, and T.Melodia, "Underwater Acoustic Sensor Networks:Research challenges", Ad Hoc Net, Vol.3,no.3 May 2005,pp.257-79

[3]. Ethem M. Sozer, Milica Stojanovic, and John G.Proakis, " Underwater Acoustic Networks" IEEE Journal of Oceanic Engineering, VOL.25, NO.1, January 2000.

[4]. Matthew Dunbabin, Peter Corke, Iuliu Vasilescu and Daniela Rus, "Data Muling over Underwater Wireless Sensor Networks using an Autonomous Underwater Vehicle" Proceedings of the IEEE International Conference on Robotics and Automation Orlando, Florida - May 2006

[5]. Anastasi, G., Conti, M., and Di Francesco, M. "Data collection in sensor networks with Data Mules: an integrated simulation analysis". In Proceedings of the 13th IEEE Symposium on Computers and Communications (ISCC 2008).

[6]. Chatzigiannakis, I., Kinalis, A., and Nikoletseas, S. "Sink mobility protocols for data collection in wireless sensor networks". In Proceedings of the 4th ACM International Workshop on Mobility Management and Wireless *Access* *(MobiWac 2006).*

[7]. P Xie, JH Cui, "R-MAC: an energy-efficient MAC protocol for underwater sensor networks" Proceedings of the International Conference on Wireless Algorithms, Systems and Applications, 2007.

[8]. Hoesel, Erman, Havinga : "Ideas on Node Mobility Support in Schedule based Medium Access" ISSNIP, 2008

[9]. Peng Xie, Zhong Zhou, Zheng Peng, Hai Yan et.al , "Aqua-Sim: An NS-2 Based Simulator for Underwater Sensor Networks." Underwater sensor networks lab, University of Connecticut. OCEANS 2009, MTS/IEEE Biloxi - Marine Technology for Our Future: Global and Local Challenges