A COMPARATIVE ANALYSIS ON SELECTIVE MAC PROTOCOLS FOR UNDERWATER WIRELESS SENSOR NETWORK

Md. Moniruzzaman¹ and Abdullah Al Mahfazur Rahman²

¹Lecturer, Department of Electrical and Electronic Engineering, Southeast University, Dhaka-1213, Bangladesh, E-mail: monir_706@yahoo.com,
²Lecturer, Department of Electrical and Electronic Engineering, Southeast University, Dhaka-1213, Bangladesh, E-mail: amrahman@seu.ac.bd,

ABSTRACT
The underwater sensor communication supports a large number of applications, like, oceanographic data collection, pollution monitoring, offshore exploration, disaster prevention, navigation and tactical surveillance data collection. In Underwater Acoustic Sensor Network (UASN), sensor nodes are deployed to a given area to do collaborative work. Underwater communication relies mainly on acoustic waves. Limited bandwidth, high propagation delay, high bit error rates and limited battery power etc are the major communication challenges for underwater communications. These issues pose great challenges in underwater Media Access Control (MAC) protocol design. Although many novel protocols are designed for terrestrial MAC protocols but they perform inefficiently when deployed directly in an underwater environment. On the other hand, a range of MAC protocols has been explored in underwater networks to meet certain communication criteria. In this paper, several contentsions based and contention free MAC protocols have been studied to understand major trend of MAC protocol developments. Special focus is given on MACA based protocols. Relative advantages and disadvantages of the discussed protocols are also highlighted and future research scope is also explored.

KEYWORDS: MACA, MAC-U, MACA-MN, MACA-APT, Underwater Wireless Sensor Network (UWSN), RTS-CTS.

INTRODUCTION
Underwater sensor networks are used for oceanographic data collection, pollution monitoring, offshore exploration, disaster prevention, assisted navigation and tactical surveillance applications [9]. For this purpose Multiple unmanned or autonomous underwater vehicles (UUVs, AUVs), equipped with underwater sensors are deployed in various locations in the sea water. Sensors nodes are also used to find out valuable natural undersea resources and to collect scientific data in collaborative monitoring missions. To make these applications sustainable, communications among the underwater sensor nodes are essential so that they may be cooperative to coordinate
their operations by exchanging configuration, location and movement information, and to forward monitored data to an onshore station.

As a physical layer communication medium acoustic signal is used in underwater networks. For long distance communication radio wave is not suitable. Through conductive sea water it only propagates long distances at very low frequencies (30-330Hz). In that case a transmitter requires large antenna and high transmission power. At high frequencies distance covered by the RF signal decreases. It is observed that at 433 MHz transmission distance shrinks to only 120cm. Optical waves do not suffer from such high attenuation but are affected by scattering. High precision narrow laser beams are required for optical communication. Thus, links in underwater networks are based on acoustic wireless communication [12].

Unique characteristic of underwater communication channel is that its bandwidth capacity is very limited and it suffers from variable delays [10]. This communication is influenced by path loss, noise, multipath fading, Doppler spread etc. Propagation delay is very severe in underwater. In radio frequency (RF), it is five times higher in underwater compared to terrestrial channels, and extremely variable. High bit error rates and temporary losses of connectivity (shadow zones) can be experienced due to the extreme characteristics of the underwater channel. Since sensor nodes are battery operated which cannot be recharged, so energy consumption is an important issue as deployed nodes require high transmission power compared to the receiving power. Moreover, collisions, overhearing, idle listening, packet overhead, etc. also play active roles in energy dissipation which limit the lifetime of a sensor device and hence, the lifetime of a network.

Underwater Medium Access Control (MAC) protocols mainly deal with above mentioned variable nature of the acoustic channels. Careful design of MAC protocols is very essential for a successful communication. Efficient use of available energy, network scalability, throughput, adaptation to the changes of node density, network topology should also be considered to design MAC protocols. There are many novel energy efficient MAC protocols, e.g., Sensor MAC (S-MAC), Time-out MAC (T-MAC) [4], Dynamic MAC (D-MAC) [5] etc. for terrestrial wireless sensor network (TWSN). But these protocols do not work satisfactorily in underwater due to its special characteristics.

On the other hand, a range of MAC protocols has been explored in underwater networks to meet specific communication criteria. The rest of the paper has been organized as follows. In section II a literary review has been made on most common protocols developed for underwater wireless sensor network. Selected Multiple Access Collision Avoidance (MACA) based protocols namely, MACA-U, MACA-MN, MACA-APT are discussed in section III, a comparison has been done in section IV and finally conclusion is drawn in section V with highlighting future research scope.

RELATED WORK

MAC protocols can be divided in two classes, contention free and contention based. Contention free protocols allocate various frequency bands, time slots or codes to different users. Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA) and Code Division Multiple Access (CDMA) are basic types of contention free protocols.

FDMA is used in Seaweb project [17] where experiment is done by deploying three clusters. FDMA was used for inter-cluster communications and within each cluster communication was
made by using TDMA. In FDMA available bandwidth is not used. This protocol is also vulnerable to fading and multipath.

Many TDMA based protocols has been developed for underwater communications. In Staggered TDMA Underwater MAC Protocol (STUMP), a set of TDMA scheduling constraints is derived and centralized and distributed algorithms are used to resolve scheduling problem [11]. At first sequence of transmissions between the conflicting nodes is determined. After fixing it, the scheduling constraints, which forms a difference equation, is solved using the Bellman–Ford algorithm. Stump shows higher throughput compared TDMA and ALOHA. But one limiting factor is that STUMP shows higher synchronization error and propagation delay. Multi-dimensional Scaling MAC (MDS-MAC) integrates time-synchronization, localization and communication scheduling for small underwater clusters [16].

Z-MAC [8] combines TDMA and CSMA. Distinguished feature of ZMAC is that its performance is robust to synchronization error, slot assignment failures and time varying channel conditions. It shows improved performance where contention is high but where channel contention is low it behaves like CSMA.

UA-MAC [2] is a TDMA based protocol which reuse channel after 2 hopes away. Slot utilization is better in UA-MAC. It also shows higher throughput compared to TDMA. U-MAC is implemented with piggyback method and less packets are exchanged which saves energy and decrease the rate of collisions.

Feasibility of TDMA based protocols are not clear as it requires long time guards to cope up with large propagation delays. It also faces synchronization problem.

A good number of CDMA based protocols have been proposed by different authors. UW-MAC [3] is a CDMA based MAC protocol which uses a closed loop distributed algorithm to set optimal transmitting power. UW-MAC shows higher throughput, less channel access delay and lower energy consumption but output is affected by multipath which is prominent in shallow water communications.

Tan and Seah combine CDMA and RTS/CTS handshaking to improve the throughput [7]. However, this approach is not suitable for UWSNs because it is difficult to assign pseudorandom codes to a large number of sensor nodes. Also, the inherent near-far problem in CDMA is not well addressed in UWSNs [6].

Cluster-based network has been proposed by Watfa, M.K. et al where each cluster has its own CDMA spreading code assigned. Communication inside each cluster is executed by exchanging request-to-send (RTS) and clear-to-send (CTS) packets, and cluster heads communicate with the sink node using TDMA [21].

Various contention based protocols has been proposed in UWSN. ALOHA [16] is the basis of many contention based protocols. Two variation of ALOHA based protocols are ALOHA with collision avoidance (Aloha-CA) and ALOHA with advance notification (ALOHA-AN) [14]. These two protocols calculate busy duration of neighboring nodes by extracting information from control packets. Slotted ALOHA has been examined by [19] but it shows the properties of pure ALOHA under high latency [1].

Carrier Sense multiple accesses (CSMA) another protocol which decreases the probability of collisions by using random back offs but CSMA becomes expensive due to large propagation delay [20].
Floor Acquisition Multiple Access (FAMA) prevents data collision by using large RTS and CTS packets [4]. As energy saving is an important issue Slotted FAMA has been proposed which lengthens time slot degrades throughput performance [22].

T-Lohi employs a novel tone-based reservation mechanism that exploits space-time uncertainty and high latency to detect collisions and count contenders, achieving good throughput across all offered load, and it employs their low power wake up receiver to significantly reduce the energy consumption. T-Lohi shows poor channel utilization during bursty traffic.

MACA BASED PROTOCOLS

In this section reservation based protocols are mainly discussed. This protocols use handshake mechanism to get access of the channel. Multiple Access Collision Avoidance (MACA) is the first protocol in this category. MACA mainly designed for TWSN which is not compatible to underwater. Many reservation based protocols for underwater are derived from original MACA. For this reason original MACA is discussed here.

ORIGINAL MACA

In MACA a source node who wants to send packets will contend for floor reservation by sending a Request-To-Send (RTS) control packet to the destination node. When destination node receives RTS it immediately replies by sending a Clear-To-Send (CTS) control packet. After receiving the CTS, the source node immediately sends data to the destination node. Any neighboring node that overhears a control packet (xRTS or xCTS) will defer its transmission, and transit to QUIET state. Data collision is minimized through the transmission deferment. In the event of CTS failure, which could either be due to CTS packet corruption or the destination node is busy, Binary Exponential Back off (BEB) algorithm is used to reschedule the packets. This protocol cannot solve exposed terminal problem due to long propagation delay in under water.

MACA FOR UNDERWATER (MACA-U)

Original MACA has modified by Hai-Heng Ng et.al so that it can be used in underwater network. Modification has been done in three areas, namely state transition rules, packet forwarding strategy, and backoff algorithm. MACA-U has five distinct states, namely, IDLE, CONTEND (CTD), Wait For CTS (WFCTS), Wait For Data (WFDATA) and QUIET [15].

When a node wants to transmit packets it goes to IDLE state to contend state. When contend state is over it transmits a RTS packet and transits to WFCTS state and waits for CTS for a fixed amount of time. Similarly after transmitting CTS, destination node undergoes to WFDATA state. To avoid collision all neighboring node who overhears xRTS or xCTS goes to QUIET state. During persistent waiting, WFCTS state source node disregards any RTS and xRTS. If it overhears any xCTS, it goes to QUIET state. Similarly, in WFDATA state, a receiver disregards any RTS, CTS, xRTS and xCTS.

In case of multihop network, in MACA-U each node maintains two separate First-In-First-Out (FIFO) queues to differentiate two classes of data traffic; one for data originated from the node
itself, and the other for received data to relay. Higher priority is given to the relay data’s queue. Thus it improves end to end throughput.

MACA BASED PROTOCOLS FOR MULTIPLE NEIGHBOUR (MACA-MN)

In MACA protocol in every handshake single packet has been transmitted. But in underwater communication handshake duration may be long due to large propagation delay and high bit error rate. This cause’s poor Channel access henceforth decreases throughput. To solve this problem new protocol has been developed named MACA-MN [13] which transfers a train of packets during each handshake to multiple receivers. In this protocol number of packets in a packet train is fixed. To transmit a complete train sufficient numbers of packets must be queued before transmission otherwise transmission will be postponed. There is no rule in this protocol to allocate unused channel access time to other nodes and in that case valuable communication resources may be wastage.

MACA BASED ADAPTIVE PACKET TRAIN (MACA-APT) PROTOCOL

MACA-APT is an improved version of MACA-MN where under single handshake multiple packet has been transferred to improve the channel utilization [18]. In MACA-APT packet size is adaptive and it does not need fixed window size for packet transmission. Moreover MACA-APT incorporates error control function in cross layer fashion via Stop & Wait Automatic Repeat Request(S&W ARQ) scheme. Most of the protocols perform error correction in another layer of protocol stack. Combining error correction and collision avoidance into same protocol causes significant saving in terms of overhead.

MACA-APT senses channel twice, one before sending RTS and another before transmitting data. This scheme reduces probability of collision. When an intended node receives an RTS packet and its current state is idle, it generates a response packet, called CTS with Report Annex (CRA). By the reception of a CRA packet, the RTS sender realizes the availability of the receiver. In CRA packets, the node also includes a report of the packets that have been correctly received in the previous session that involved these two nodes. This is the way the sender gets an acknowledgment for correctly delivered packets. The CRA sender also includes the expected session duration, in order to inform its neighbors and thus avoid unwanted channel accesses. When any neighbor receives the CRA, it notes down the duration of the upcoming session and moves to the sleep state if it is not among the intended receivers and thus saves energy.

It also includes session duration in every data packets which is helpful for newly joined nodes to know the duration of current communication and thereby move back to sleep state again. Upon receiving CRA’s from all expected nodes a sender goes to data transmission state. If it does not receive CRA’s from all intended nodes then it considers that there is a probability of collision and refrain from transmission of data packets. In this way collision may be avoided which increases normalized throughput. After receiving all CRA packets channel is sensed by the sender again for a random time. It poses its transmission and goes to sleep state if it receives data packets from another node. MACA-APT avoids of using explicit ACK back to the sender which is inconvenient to send multiple packet to multiple users. CRA packet performs this duty.

FINDINGS AND OUTCOMES

Throughput performance of MACA-U compared to MACA and ALOHA is shown in figure 1.
Figure 1: Throughput Comparison MACA-U, CS-MACA, Pure Aloha and Original MACA [15]. After reviewing MACA-U protocols findings can be summarized as follows:

1. MACA-U performs 20% higher than original MACA for the saturation throughput.
2. By disregarding any overheard xRTS during WFTS state concurrent data transmission is possible between the neighborhoods which can system throughput.
3. This protocol is more appropriate for short range multi-hop underwater networks.
4. As the inter-nodal distance increases throughput decreases due to larger propagation delay in exchange of RTS-CTS packets.
5. MACA-U shows stable throughput for all range of data packet sizes.
6. It is very costly because in each successful handshake single data packet has been sent.
7. MACA-U can be improved using packet train concept.

Performance of MACA-MN has been evaluated comparing its outcome with to MACA and Aloha-AN. Throughput comparison among these protocols is shown in figure 2.

Figure 2: Throughput comparison with MACA and Aloha-AN[13].

Findings of MACA-MN can be summarized as follows:

1. MACA-MN shows highest throughput compared to MACA as it uses train of packets.
2. Larger propagation delay has less impact on performance as it uses fewer handshakes compared to MACA or MACA-U.
3. In MACA-MN hidden terminal problem is not completely solved so, there is probability of data collision.
4. Channel may not be efficiently utilized if number of data packets is not sufficient in queue for transmission.
5. MACA-MN shows less transmission delay compared to MACA.

Throughput performance of MACA-APT is compared to MACA-MN in figure 3: It is clear that MACA-APT outperforms MACA-MN as number of packets in packet train is not fixed. Another reason of increase throughput of MACA-APT is that it does not undergoes data transmission state until gets CRA packets from all intended nodes within a certain time period. It ensures collision free transmission. Otherwise transmission is abandoned to avoid uncertain collision.

![Figure 3: Normalized Throughput vs. Normalized Packet Generation rate/node [18].](image)

Other findings of MACA-APT are:

1. If number of packets in a packet train is high then a node can transmit higher number of packets. But it causes other nodes to wait for a longer time to get a chance to transmit data.
2. After waiting for a long time, all the waiting nodes may simultaneously try to access the channel. This leads to high probability of collision among APTs RTS/CRA packet.
3. Due to high contention a node may fail to access the channel. In that case channel will be underused.
4. If erroneously multiple nodes get access of channel, packet trains of multiple channel may collide.
5. If packet size is low then channel will be underused.

Above discussed protocols focuses on certain issues such as throughput, channel utilization etc. But some other issues such as hidden and exposed terminal problems, energy efficiency etc are not well addressed.
CONCLUSION

MACA-APT can be considered as a benchmark to develop more advance MAC protocols which will mitigate the exposed and hidden terminal problems. This protocol should be energy efficient and may also share the channel with other nodes so that simultaneous transfer of packet trains is possible. New protocols may be developed by arranging nodes in virtual clusters. All the nodes within a cluster would contend for the channel within a fixed contention period and a node which is starving for the longest duration to get access to the channel would be preferred. Coding theory may be applied so that nodes can transmit data simultaneously without collisions.

REFERENCES


