# Testbed-based Performance Evaluation of Handshake-free MAC Protocols for Underwater Acoustic Sensor Networks

Yashar M. Aval, Yu Han, Andrew Tu, Stefano Basagni and Yunsi Fei
Department of Electrical and Computer Engineering
Northeastern University, Boston, MA 02115

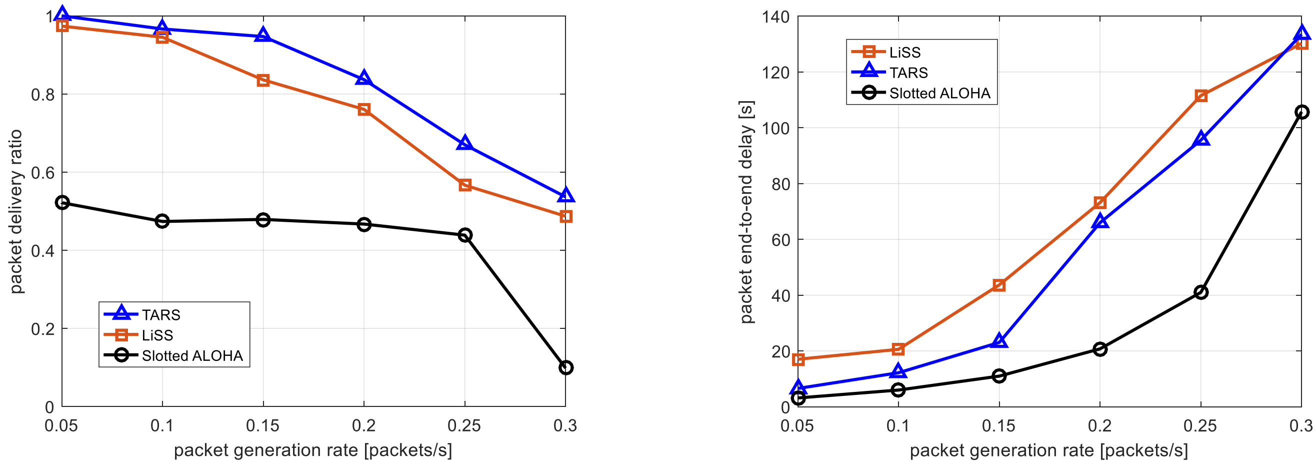
## Extended Abstract

Designing and implementing efficient medium access control (MAC) for underwater acoustic sensor networks (UASNs) is challenging due to the long propagation delays of the underwater acoustic channel and its unique spatial-temporal variability. MAC protocols successfully used for terrestrial networks are not as effective for accessing the underwater channel because of the many differences between the radio channel and its acoustic underwater counterpart. Many radio protocols based on channel reservation through a "handshake" mechanism (e.g., an RTS/CTS exchange à la IEEE 802.11) between the sender and the receiver incur overhead and disproportionate delays underwater. In fact, many protocols notoriously inefficient for radio access, such as ALOHA-like approaches, become effective ways of accessing the underwater channel because of little overhead and higher channel utilization. In other words, protocols that avoid the overhead of channel reservation mechanisms ("handshake-free" protocols) result in good channel access, allowing robust packet communication even at higher traffic loads.

In this paper we investigate the performance of handshake-free MAC protocols for underwater communications, where overhead and higher delays are avoided by transmitting packets without previous channel reservation and where interferences are reduced, and throughput increased, by some form of probabilistic channel access. The protocols we consider are recently proposed, state-of-the-art solutions, namely, the Traffic-Adaptive Receiver-Synchronized (TARS) protocol by Han and Fei [1], and the Lightweight Stochastic Scheduling (LiSS) protocol proposed by Marinakis et al. [2]. TARS combines the low overhead of handshake-free protocols with a receiver-synchronized approach that adjusts the packet transmission time in a slot to align packet receptions for collision reduction. A queue-aware utility-optimization framework is formulated to dynamically determine the optimal transmission strategy that maximizes the network throughput, which takes both packet interference and data queue status into consideration. Such optimal transmission strategy is traffic adaptive and can be achieved in a distributed manner, thus being suitable for actual implementation in multi-hop UASNs. Similar to TARS, LiSS is also a stochastic MAC protocol targeting network-wide optimization. Scheduling packet transmission for optimized throughput is determined by the network topology, without explicitly considering traffic. To demonstrate the effectiveness of handshake-free protocols for channel access, we compare the performance of TARS and LiSS to that of ALOHA, which is the exemplary handshake-free protocol. As TARS and LiSS assume that nodes are synchronized, we consider the slotted version of the ALOHA protocol.

We implemented the three protocols in Matlab, running on small-factor computers controlling three Teledyne Benthos SM-975 acoustic modems. The modems were submerged a positioned in a line in an indoor rectangular tank filled with fresh water. Given the dimension of the tank, the distance between two adjacent modems was about 1 meter. The protocol stack of each of the modem consists of three basic layers: Application, for traffic generation, MAC for channel access, and an interface to the physical layer for controlling the modem. The top layer takes care of the packet generation function, which randomly generates data packets according to a Poisson distribution with varying parameter, corresponding to low traffic, medium and high traffic conditions. In particular, at low traffic on average each node is given a packet to transmit every $60$ seconds, which corresponds to a network-wide generation rate of $0.05$ packets per second. At high traffic each node receives a packet every $10$ seconds, for a network wide load of $0.3$ packets per second. The corresponding packet generation rate is identical for all modems. The payload of each packet is $41$ bytes. The middle layer implements channel access, i.e., it is either TARS, LiSS or slotted ALOHA. The MAC transmit function reads the data packets from the queue and calls the function of the physical layer. The MAC layer also keeps track of the acknowledgments from the receiver, and upon time out (for packet collision) retransmits the packet. The receiver decodes and stores the received data packets. At the lowest level, we program the direct interface to the modem through a serial port connection. The combination of this interface and the modem acts as the physical layer.

Since all protocols require node synchronization, we develop a scheme for time synchronization across the network nodes. As our topology configuration is a single-hop networks, i.e., each node is in the transmission range of every other node, we designate a node to be the master, and use its clock as the reference clock for the network. Any other node receives the timing information from the master and adjusts its own clock accordingly. For slotted ALOHA we dimension the slot duration to accommodate packet transmission and propagation delay. The backoff of slotted ALOHA is implemented so that, upon




(a) Packet delivery ratio

(b) End-to-end packet delay

Fig. 1: Packet delivery ratio (PDR) and end-to-end delay for three MAC handshake-free protocols in our setting with three SM 975 acoustic modems.

collision, a node will persistently retransmit the timed-out data packet with probability $p$ until either the packet is received successfully or the maximum allowable retransmissions threshold is reached. In the latter case, the packet is discarded. The probability $p$ used in our experiments has been set to $1/3$. Because of their definition, the slot duration in both TARS and LiSS only needs to consider the packet transmission time. The threshold for maximum allowable retransmissions has been set to 3 for all three protocols. In other words, if after $4$ attempts a packet is not correctly acknowledged, that packet is discarded. The TARS implementation includes two major differences compared to that of slotted ALOHA. First, TARS uses a receiver synchronization approach, where nodes compensate for the propagation delay by sending data packets with transmission phases in a slot to guarantee no cross-slot packet receptions. Second, TARS uses an optimal adaptive transmission strategy (i.e., the optimal sending probability) that is dynamically determined by a throughput-optimization framework and changes with data loads and network topology to increase channel utilization while controlling packet collisions. The LiSS implementation differs from that of TARS in two ways. First, it uses the traditional transmitter synchronization approach as slotted ALOHA, where packets are transmitted at the beginning of a slot. Second, its optimal transmission strategy is only determined by the network topology, without adapting to possible variation of the data traffic.

We compared the three protocols with respect to their packet delivery ratio, namely, the percentage of the packets successfully delivered to their destination, and with respect to the average packet end-to-end delay, namely, the time that it takes to (successfully) deliver a packet. The packet end-to-end delay includes the queuing delay, transmission delay, and propagation delay. Our results are shown in Fig. 1.

At low to medium traffic, TARS and LiSS are capable of delivering almost all of the data packets. TARS achieves the highest PDR because of its optimized transmission strategy and collision reduction by interference alignment. LiSS shows lower PDR than TARS (especially at medium traffic) due to its inability of adapting to varying traffic. Slotted ALOHA shows low PDR at all traffic rates because of the higher number of packet collisions and retransmissions, which lead to discarding a high number of packets. For the packet end-to-end delay, TARS shows better delay than LiSS at low to medium traffic, because of its more aggressive transmissions with controlled packet collisions. Slotted ALOHA exhibits the smallest delay among the three protocols because latency is computed only over successfully delivered packets. We observed that the few packets delivered by slotted ALOHA are often delivered at the first attempts, i.e., with small delays.

In the future, a set of experiments in an outdoor pool are scheduled to be conducted in May/June 2016, followed by the experiments in the ocean at the Northeastern University Marine Science Center (MSC) in Nahant, MA. We plan to evaluate the performance of the three protocols in networks with up to 7 nodes with respect to packet delivery ratio, packet end-to-end delay, number of packet retransmissions and power consumption.

## References

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