Analysis of Aloha Protocols for Underwater Acoustic Sensor Networks

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***Abstract*— In this paper, we present a study on Aloha and Slotted Aloha protocols for Underwater Sensor Networks (UWSN). Such simple random access protocols allow sensor nodes to communicate in UWSN. We present a simple mathematical analysis as well as simulations to show the performance of Aloha and Slotted Aloha in the acoustic environment. Our results show that long propagation delay of acoustic signals prohibits the coordination among nodes (e.g., slotted methods), and thus, it does not yield any performance gain.**

I. Introduction

Underwater Sensor Networks are networks composed of nodes with sensor, communication and processing abilities that operates underwater. This environment brings new challenges, such as signal attenuation and high delay. The technology also brings a broad range of applications for underwater acoustic sensor networks. In this paper we present an analysis of a family of protocols, Aloha and Slotted Aloha, helping in identifying the behavior of the protocol under a different environment and learn from it, aiding in designing new protocols.

Understanding the nuances of the protocols, how they work and can be used in new paradigms is a challenge that we address in this paper. Based on a solid mathematical model, we describe the results analyzing ALOHA and Slotted Aloha and, we believe, opens the door for better designing MAC protocols for underwater applications.

II. Aloha

ALOHA is a class of MAC protocols that do not try to prevent packet collision. The protocol works as follow. Every computer that has data to send, sends the data. If two systems transmit packets at the same time, a collision occurs. In that case, a retransmission occurs. Aloha can be improved by having discrete timeslots. A computer can no long send packets at anytime, but just at the beginning of a timeslot, and thus chances of collisions are reduced. This version is referenced as Slotted Aloha. In this paper, we focus on the impact of long propagation delay of acoustic signals on those protocols.

III. UWSN

Ocean covers about two thirds of the earth surface. Those areas are uninhabited and largely unexplored. Through the advance of technology and use of sensor networks it is now possible to construct networks with many applications. In underwater networks, the predominant physical layer technology are acoustic signals. In fact, radio waves propagate at long distances through conductive sea water only at extra low frequencies (30 to 300 Hz). Optical waves do not suffer from such high attenuation but are affected by scattering. Thus, links in underwater networks are based on acoustic wireless communications [1].

The acoustic channel has large signal propagation delay. Usual network communication is based on electromagnetic waves travelling at the speed of about $3 * 10^8 m/s$. The speed of sound is roughly $1.5 * 10^3 m/s$. The difference in speed propagation can have a great impact on how protocols works.

We also have to look at narrow bandwidth with high attenuation. Current bandwidth and length product is about 40 kbps x km [2]. Current technology for Underwater Acoustic Modem Models present modems that are directional or omnidirectional Transducer. They work on a range up to 350 meters and depth up to 200 meters [3].

IV. Model and Results

In this section we describe the model to analyze ALOHA for UWSN. We first look at pure aloha and then slotted aloha. Our goal is to help in identifying the behavior of the protocol under a different environment and learn from it, aiding in designing new protocols.

Our analysis is based on mini-slots, which is supposed to be defined as a packet of the same size. If it would be the case where they are non-uniform size, then we can define T which is the transmission time of the max size packet.

A. Pure Aloha

When analyzing Aloha in ground communication, one can see that a packet sent at time t will collide with other packets sent in time [t-1, t+1]. This can be visualized in Figure 1. The figure shows three stations that have sent packets. The first sent the packet after time $t-1$, the second at time t and the third before time $t+1$. Since all the packet overlap with part of another, no transmission was successful.

In underwater acoustic communication we can look at Aloha using a similar approach. However, this time we have to consider the propagation delay. Instead of looking at the time

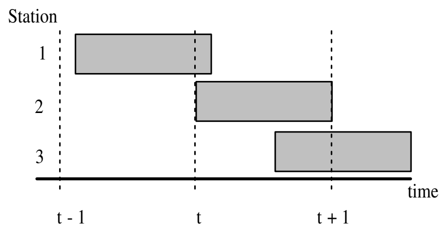

Fig. 1. Aloha collisions.

the packet was sent, we look at the time that the packet is received at the destination. The transmission of a packet is successful if the packet does not collide with another packets at the destination.

To emphasize the difference that propagation delay can cause, we will look at an intuitive example. It is based on the same transmission explained in figure 1. After time $t-1$, the first node sends a message. At time t, the second node sends a message. Also, the first message keeps propagating. Both signals will eventually meet, forming constructive and destructive waves. After that, the signals will keep going in that direction. At time $t+1$, the signal sent by node 2 will continue to propagate and the signal from message sent by node 1 will reach node 2. Since the message reaches node 2 without collision, the message is considered to be successful. Note that if it were radio signals, this would result in a collision.

We want to calculate the probability that a message is successfully sent at time t. Consider that a node sends a message when it flips a coin and see heads, and waits when see tail. At time t, a message is successfully sent if and only if exactly one of the nodes sends a message at time t and all the others messages do not collided at time t. This mean that a message that takes Δt to arrive is not transmitted at time $t-\Delta t$. This is the same as exactly one of the nodes flips heads and all others see tail, at different times.

$$Pr(E_i) = p(1-p)^{n-1} \quad (1)$$

where $0 \leq p \leq 1$.

The best performance is determined by

$$\lim_{n\to\infty}(1-\frac{1}{n})^{n-1} = \frac{1}{e}. \quad (2)$$

B. Slotted Aloha

Slotted Aloha is a modified version of Aloha which introduced discrete time slots. Time is divided into equal length slots. A message is sent only on the beginning of a time slot.

Instead of giving a formal proof, here we present an intuitive explanation of the performance of Slotted Aloha in UW context. Assuming that there is a way to synchronize the nodes so that they could implement Slotted Aloha. Again, we have to consider the propagation delay. Instead of looking at the time the packet was sent, we have to look at the time the packet is received at each node. Although the nodes sent the messages in pre-defined time slots, there is no guarantee that they will arrive in time slots. Therefore, Slotted Aloha in underwater has no effect different from Aloha except the cases where the propagation delay is a multiple of the time slot interval. In other words, the distance between nodes, when divided by the sound speed, results in an integer of time slots. The probability that all nodes are randomly place in this scenario is zero. Therefore, the best utilization for Slotted Aloha in underwater is the same as Aloha.

V. Experiments

We modified Qualnets simulator in order to simulate underwater environments. We implemented a new medium and propagation model for underwater. The signal speed was set to the speed of sound $1500m/s$. In our experiments, we used a bandwidth of 20Kps and a channel frequency of 50KHz. Figure 2 show the graphic of S (number of packets successfully transmitted) versus G (number of packet transmission attempted) for Aloha, Slotted Aloha and the analytical function for best utilization. The figure shows that the performance of Aloha and Slotted Aloha is about the same.

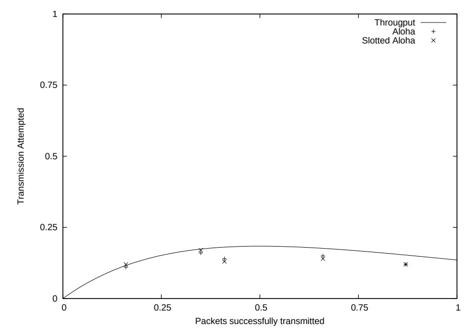

Fig. 2. Experiments results.

VI. Conclusions

Underwater Wireless Sensor Network (UWSN) is a novel networking paradigm to explore aqueous environments. The characteristics of UWSNs, such as low communication bandwidth, large propagation delay, floating node mobility, and high error probability, are significantly different from ground-based wireless sensor networks [4] and that directly affect how the protocols works. In this paper we have shown that Aloha in underwater is affected by propagation delay. Our simple analysis and simulation results show that Slotted Aloha, that uses discrete time slots, exhibits the same utilization as non-Slotted Aloha.

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