Fair MAC Protocol based on Adaptive DIFS for Underwater Acoustic Sensor Networks

HYEONG-WOOK AHN and SUNMYENG KIM
Department of Computer Software Engineering
Kumoh National Institute of Technology
61 Daehak-ro, Gumi, Gyeongbuk
SOUTH KOREA
anbriaao@naver.com and sunmyeng@kumoh.ac.kr

Abstract: - Underwater acoustic sensor networks (UASNs) have become a very active research area in recent years. Compared with wireless networks, UASNs have long propagation delay of acoustic signals, which pose challenges to the design of medium access control (MAC) protocol. There is a spatial unfairness problem caused by spatial-temporal uncertainty. The packet arrival time at the receiver depends on both the distance between the sender and receiver and the sender's transmission time. Therefore, it is hard to provide the fairness to channel access among senders in UASNs. In this paper, we propose a fair MAC protocol based on adaptive DIFS (DCF inter-frame space) to solve the unfairness problem. In CSMA based MAC protocols, if the channel is idle for a fixed DIFS period of time, then a sender starts its own backoff process. In the proposed protocol, the DIFS value is dynamically set according to the distance between the sender and the receiver. Senders with close distances from the receiver have large DIFS values, and distant senders have small DIFS values. The proposed protocol addresses the unfairness problem by equalizing channel access probabilities of all nodes regardless of the distance.

Key-Words: - Adaptive DIFS, Distance, Fairness, MAC, Propagation Delay, UASN

1 Introduction

Underwater acoustic sensor networks (UASNs) are a class of sensor networks deployed in underwater environments [1]. UASNs have attracted much attention in recent years due to their potential in various applications. There are significant differences between UASNs and wireless networks because of the unique features such as low available bandwidth, long propagation delay, and dynamic channels in acoustic modems. These features pose challenges to medium access control (MAC) protocol design [2], [3]. And, MAC protocols for wireless networks cannot be directly applied to UASNs because the work is based on high data rates and negligible propagation delays. Especially, carrier sense multiple access / collision avoidance (CSMA/CA) cannot prevent packet collisions well among nodes due to the long propagation delays in UASNs. Therefore, it is necessary to design new MAC protocols to take into account the different features.

Significant efforts have been devoted to the underwater MAC protocol design to overcome the negative effects introduced by the harsh underwater environments [3], [4]. Most of them are based on the handshaking in order to reduce the collision probability in UASNs. They use control packets such as Request-to-Send (RTS) and Clear-to-Send (CTS) to contend and reserve channel for data transmissions.

In [5], authors indicated the spatial-temporal uncertainty problem in underwater environment. It significantly decreases network performance of CSMA based protocols. In [6], authors described that the long propagation delay of acoustic media causes spatial unfairness problem. Senders near the receiver occupy the channel quickly. On the contrast, other senders away from the receiver rarely occupy the channel.

In this paper, we propose a fair MAC protocol to solve the unfairness problem, called adaptive DIFS based fair MAC (ADF-MAC). In CSMA based MAC protocols, if the channel is idle for a fixed DIFS period of time, then senders start their backoff processes. In the proposed protocol, the DIFS value is dynamically set according to the distance between the sender and the receiver. Senders close to the receiver have large DIFS values, and distant senders have small DIFS values. The proposed protocol addresses the unfairness problem by equalizing channel access probabilities of all senders regardless of the distance through adaptive DIFS.

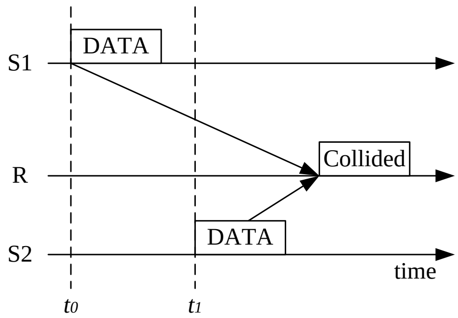
The paper is organized as follows. We discuss related work on MAC of UASNs in section 2. In section 3, the proposed ADF-MAC protocol is described in detail. Finally, we draw conclusions in section 4.

2 Related Work

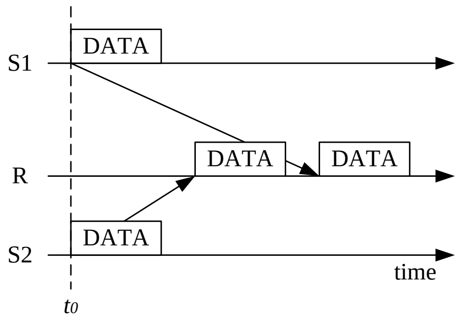
In this section, we first discuss the spatial-temporal uncertainty and spatial unfairness problem. And then, we described the previous MAC protocols proposed to address the unfairness problem.

2.1 Spatial-Temporal Uncertainty

Nodes in terrestrial wireless networks can estimate the channel status easily since the propagation delay is very short and negligible. However, in UASNs, it is essential to consider the location and transmission time of the node due to the long propagation delay of acoustic media [7]. Spatial-temporal uncertainty is defined as two-dimensional uncertainty in determining a collision at a receiver. The packet collision at the receiver depends on both the distance between the sender and receiver and the sender's transmission time.



(a) Different transmission time but collision at R



(b) Same transmission time, no collision at R

Fig. 1 Example of spatial-temporal uncertainty

Fig. 1 shows an example of the spatial-temporal uncertainty. In Fig. 1, there are two senders (S1 and S2) and one receiver (R). In Fig. 1(a), two senders transmit their data packets at the same time. However, the receiver receives the packets at different time due to the different propagation delay. In another works, there are no collision at the receiver. On the other hand, two senders transmit their packets at the different time (see Fig. 1(b)). The packets arrive at the receiver at the same time and are collided.

2.2 Spatial Unfairness Problem

The long propagation delay of acoustic media causes spatial unfairness problem. Nodes near the receiver occupy the channel easily. On the contrast, other nodes away from the receiver have very low channel occupancy probability.

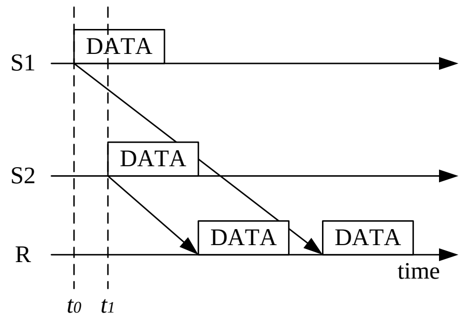


Fig. 2 Example of spatial unfairness problem

Fig. 2 describes an example of the spatial unfairness problem. In Fig. 2, the sending time of the sender S1 is earlier than the sender S2. However, the receiver R receives the packet of S2 earlier than that of S1 since S1 has longer propagation delay than S2. Propagation delay of signal is proportional to the distance between sender and receiver.

2.3 Previous MAC Protocols

SF-MAC in [7] and RET-MAC in [8] protocols were proposed to solve the spatial unfairness problem. They adopt the RTS/CTS handshaking method and are based on receiver.

Both protocols determine the earliest sender of RTS packet and transmit CTS packet to it. When a receiver receives an RTS packet from a sender, the receiver delays the CTS packet for the RTS contention period (CP) time without sending it immediately to avoid collision caused by the spatial-temporal uncertainty. The RTS CP time begins when the receiver receives the first RTS packet. The receiver continues to receive RTS packets from other senders for the RTS CP time. At the end of the RTS CP time, the receiver determines which sender sent the RTS packet first among the senders.

Fig. 3 shows a basic operation of the SF-MAC and RET-MAC protocols. In Fig. 3, there three senders (S1, S2, and S3) and one receiver (R). The receiver receives the first RTS packet from the sender S3 and starts its RTS CP time. It continues to receive RTS packets from the senders S1 and S2 during the RTS CP time. It determines that the sender S2 transmitted the RTS packet first, and then responds with a CTS packet to the sender S2.

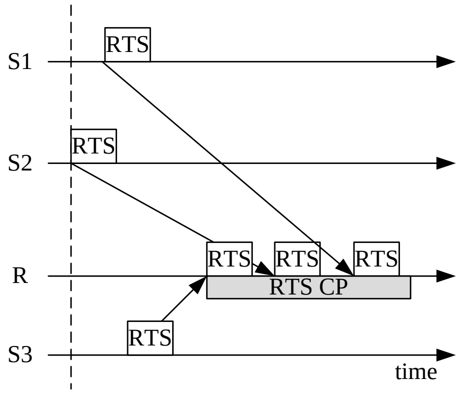


Fig. 3 Basic operation of SF-MAC and RET-MAC protocols

SF-MAC protocol determines the earliest sender of RTS packet by probability rule. RET-MAC protocol assumes that clocks are synchronized. In SF-MAC and RET-MAC protocol, the period of RTS CP time is long. It seriously affects network performance.

3 Proposed ADF-MAC Protocol

The proposed protocol uses the RTS/CTS handshaking method and is based on sender.

In CSMA based protocols, if the medium is sensed to be free for a DIFS time interval, a sender begins its backoff process. If the medium is busy, the sender defers its backoff process until the end of the current transmission and then it waits an additional DIFS interval. If the backoff counter reaches zero, the sender transmits an RTS packet to the receiver.

The previous protocols use a fixed DIFS value as following:

$$DIFS = SIFS + (2 * aSlotTime) \quad (1)$$

where, *SIFS* is a short interframe space and *aSlotTime* is the duration of a slot time.

In the proposed SDF-MAC protocol, the DIFS value is dynamically set according to the distance between the sender and the receiver.

In order to obtain the distance, we use the propagation delay between the sender and the receiver. The sender estimates the RTT (Round Trip Time) and calculates the propagation delay.

When a sender has a data packet to send to a receiver, it converts the propagation delay to the distance as following:

$$D_{(i,j)} = Pd_{(i,j)} / v \quad (2)$$

where, $D_{(i,j)}$ and $Pd_{(i,j)}$ are the distance and the propagation delay between the sender i and the receiver j, respectively. v is the speed of acoustic signal and is 1,500 m/s.

The DIFS value in the proposed ADF-MAC protocol is dynamically set according to the distance between the sender and the receiver. The DIFS value is in inverse proportion to the distance.

The DIFS value ($DIFS_{(i,j)}$) for the proposed protocol is calculated as following:

$$DIFS_{(i,j)} = DIFS + SN_{(i,j)} * aSlotTime \quad (3)$$

where, $SN_{(i,j)}$ is a value obtained by changing the distance in slot time unit. It is calculated as following:

$$SN_{(i,j)} = \begin{cases} 0, & if\ D_{(i,j)} < aSlotTime \\ \left\lfloor \dfrac{TR_{max}}{D_{(i,j)}} \right\rfloor, & else \end{cases} \quad (4)$$

where, TR_{max} is the maximum transmission range. $\lfloor x \rfloor$ rounds to the largest integer smaller than or equal to x.

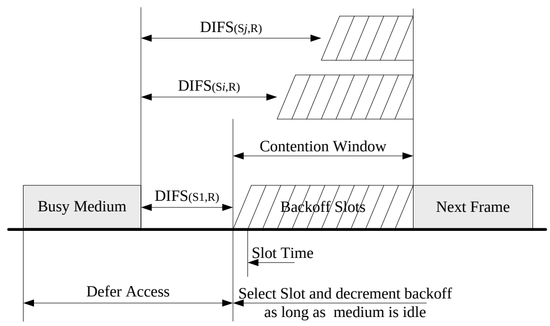


Fig. 4 DIFS relationships in ADF-MAC protocol

Fig. 4 shows DIFS relationships in the proposed ADF-MAC protocol. Senders close to the receiver have large DIFS values, and distant senders have small DIFS values.

4 Conclusion

UASNs have long propagation delay of acoustic signals. Therefore, there is a spatial unfairness problem caused by spatial-temporal uncertainty. In this paper, we proposed a new MAC protocol to solve the unfairness problem. The proposed protocol sets the DIFS value based on the distance between the sender and the receiver. The proposed protocol addresses the unfairness problem by equalizing channel access probabilities of all nodes regardless of the distance through adaptive DIFS.

References:

[1] P. Casari and M. Zorzi, Protocol Design Issues in Underwater Acoustic Networks, *Computer Communications*, Vol. 34, No. 17, 2011, pp. 2013-2025.

[2] Y. Zhu, Z. Peng, J.-H. Cui, and H. Chen, Toward Practical MAC Design for Underwater Acoustic Networks, *IEEE Transactions on Mobile Computing*, Vol. 14, No. 4, 2015, pp. 872-886.

[3] L. Pu, Y. Luo, H. Mo, S. Le, Z. Peng, J.-H. Cui, and Z. Jiang, Comparing Underwater MAC Protocols in Real Sea Experiments, *Computer Communications*, Vol. 56, 2015, pp. 47-59.

[4] Y. Zhang, Y. Chen, S. Zhou, X. Xu, X. Shen, and H. Wang, Dynamic Node Cooperation in an Underwater Data Collection Network, *IEEE Sensors Journal*, Vol. 16, No. 11, 2016, pp. 4127-4136.

[5] C.-C. Hsu, M.-S. Kuo, C.-F. Chou, and K. C.-J. Lin, The Elimination of Spatial-Temporal Uncertainty in Underwater Sensor Networks, *IEEE/ACM Transactions on Networking*, Vol. 21, No. 4, 2013, pp. 1229-122.

[6] A. A. Syed, W. Ye, and J. Heidemann, Comparison and evaluation of the T-Lohi MAC for underwater acoustic sensor networks, *IEEE Journal on Selected Areas in Communications*, Vol. 26, No. 9, 2008, pp. 1731-1743.

[7] W. H. Liao, C. C. Huang, SF-MAC: A Spatially Fair MAC Protocol for Underwater Acoustic Sensor Networks, *IEEE Sensors Journal*, Vol. 12, No. 6, 2012, pp. 1686-1694.

[8] S.-M. Xiong, C. Yuan, L. Tian, and Y. Zhan, RET-MAC: A New Fair MAC Protocol for Underwater Acoustic Sensor Network, *International Journal of Distributed Sensor Networks*, Vol. 9, No. 6, 2013.