Advances in Engineering Research (AER), volume 61
International Conference on Mechanical, Electronic, Control and Automation Engineering (MECAE 2017)

An Improved Time Division Multiple Access Protocol in UWSN

Yi Liang [1, a], Pingping Wen [2, b], Haoxian Wang [1, c], Zhanfeng Zhao [1, d]

[1]School of Information and Electrical Engineering, Harbin Institute of Technology at Weihai, Weihai 264209, China

[2]Alcatel-Lucent Shanghai Bell, Shanghai 201206, China

[a]774207616@qq.com, [b]purplelixl@126.com, [c]915614496@qq.com, [d]56044075@qq.com

Keywords: Medium access control layer, time division multiple access, random access protocol.

Abstract. The development of underwater wireless sensor networks (UWSN) is attracting more and more attentions. The MAC layer protocols which are the important part of the network, dominate the method of each node sharing the channel, thus affect the performance of throughput, latency, energy consumption and other aspects of the network. In this paper, an improved time-division underwater multiple access protocol is discussed, which allocates slots for each node according to the distance. The simulation reveals that the improved protocol has lower latency, better throughput performance, and higher energy efficiency than random access protocol CSMA/CA and handshake protocol Slotted-FAMA.

1. Introduction

With the development of modern communication technology, the ocean and sky stereoscopic information network is gradually forming. As an important part of the integrated network, UWSN is of great significance to the resources development and information collection. However, the development of UWSN is lagged behind [1-2].

Underwater acoustic communication has its own characteristics compared with the electromagnetic wave communication [3-4].

(1) Limited channel bandwidth: Underwater acoustic communication can be used in the bandwidth range of about 20 kHz to 50 kHz, in the communication range between 100m and 1000m.

(2) High propagation latency: Underwater acoustic propagation speed is about 1500m/s, which affected by various factors. Meanwhile, High propagation latency exacerbates the problems of hidden terminal and exposed terminal.

(3) Limited resource: Underwater sensor nodes are mostly powered by batteries, so electric energy, processing capacity and communication capacity are limited.

Due to the unique characteristics of the underwater acoustic channel, the land wireless communication protocols should be improved to fit the special situation. In this paper, based on the analysis of the underwater acoustic MAC protocols, an improved time division multiple access protocol is proposed.

2. Overview of MAC Protocols for UWSN

According to the channel access mode, MAC protocols of UWSN can be divided into two types: contention-based MAC protocols and contention-free MAC protocols [5-6].

2.1 Contention-based MAC Protocols

Contention-based MAC protocols obtain the channel access right through the random competition, which have better flexibility. Many Contention-based MAC protocols have been proposed, such as ALOHA, CSMA, MACA, FAMA and their improvements.

CSMA is a representative class of random access protocols where all nodes have to sense the channel for a certain period of time before the channel access. Collision can be effectively reduced through the channel sensing and random backoff mechanism. With the increase in network propagation latency, channel sensing time limits the protocol efficiency in UWSN. Simultaneously, the problems of hidden and exposed terminal significantly decrease the transmission performance of UWSN.

FAMA is a representative of handshaking protocols. Through the request to send (RTS) and clear to send (CTS) handshake control signals, nodes get access to the channel. Meanwhile, non-persistent carrier sensing mechanism is adopted to reduce the packet collision probability. In order to improve the throughput and channel utilization, FAMA protocol allows nodes to send multiple frames consecutively after the handshakes succeed. Slotted-FAMA introduces the slot mechanism based on the FAMA [7], which defines the communication slots. It reduces the data collision probability further, but still limited by the channel utilization.

2.2 Contention-free MAC Protocols

Contention-free MAC protocols assign the channel to different nodes according to the multiplexing method. Under certain conditions, network nodes can use the channel alone, which avoid the data collision phenomenon and improve the channel utilization. Currently, CDMA, TDMA and their improvements are mostly adopted in UWSN [8-10].

CDMA is one of the significant research directions of underwater acoustic MAC protocols. The key issue is how to combine with other protocols and choose appropriate power control algorithm.

TDMA assigns different transmission slots for each node, and improves the channel utilization significantly. But the land wireless TDMA protocol is hard to apply underwater, owning to the time synchronization problem. In this paper, an improved TDMA underwater MAC protocol is discussed to optimize the problem, and the simulation results indicate its validity and rationality.

3. ASSTDMA Protocol

TDMA protocol is mostly adopted in centralized network or star network, which consists of a master node and several sub nodes.

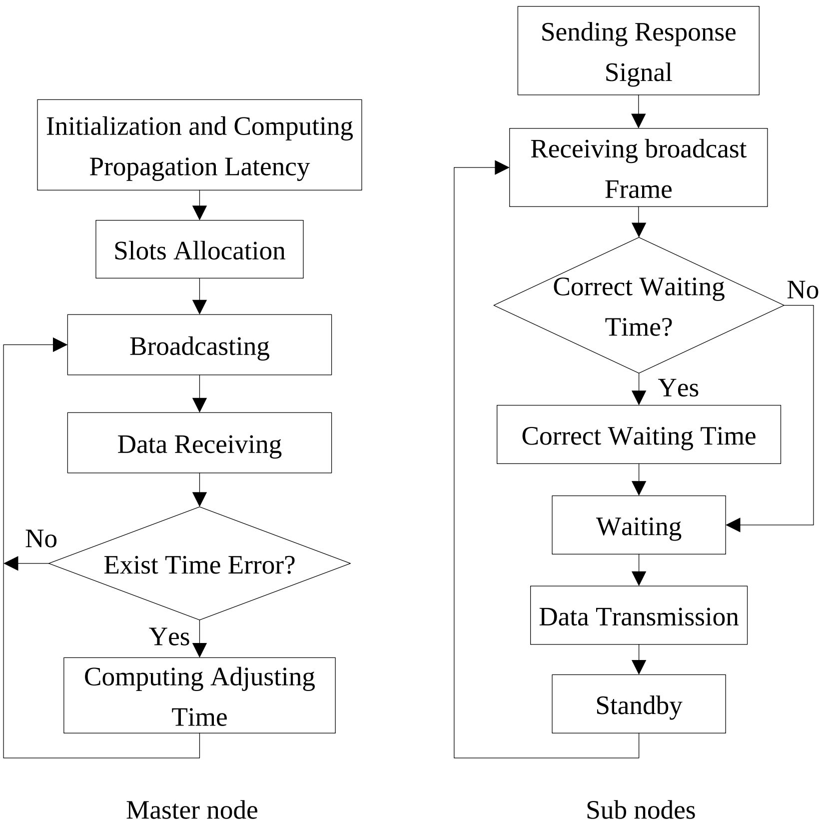

Fig. 1 The work procedure of master node and sub nodes

Considering the strict requirement of TDMA protocol for time synchronization, the master node correct the errors based on the arrival time of data frames. Owning to avoid the global clock synchronization, the ASSTDMA is uncomplicated and efficient. Figure 1 illustrates the work procedure of master node and sub nodes.

The ASSTDMA protocol consists of slots allocation, broadcasting, data transmission and clock correction.

The slots allocation process is divided into the propagation latency estimation and time slots allocation. After the network is initialized, the master node broadcasts the registration instruction to the whole network. When the sub nodes receive the registration instruction, they return the respective response signal immediately. According to the arrival time of each sub nodes response signal, the master node can obtain the double propagation latency.

If the collision happened, we can take multiple rounds of registration and adopt random backoff algorithm, until the whole network registration is completed. Then the master node sorts the propagation latency from low to high and allocates transmission slots for sub nodes. The node index is corresponding to propagation latency. Meanwhile, the guard interval *Tg* is left between each transmission slots to avoid data collision.

The master node broadcasts to the network after the slot allocation stage. Broadcast frame acts as a time reference and sends the time correction signal to sub nodes.

The master node waits for the time of τ (maximum propagation latency plus the minimum propagation latency of the whole network) and then starts receiving the data of first slot. Until all the slots of data are received, a complete period T is finished.

When the period is completed, the master node analyses the collision risk (if received adjacent slots of data interval is less than *Tg*/2, there is a collision risk) according to the data arrival time. Then it recalculates the send adjustment time of sub nodes. In the next broadcasting stage, the master sends the frame that consists of the new adjustment time. Figure 2 illustrates the duty cycling of master node and sub node n.

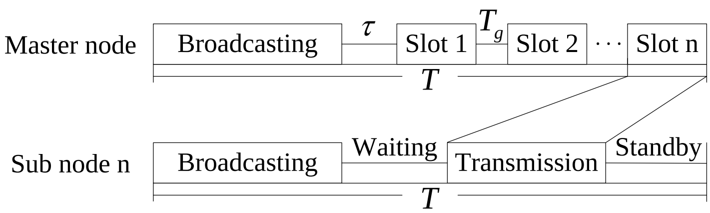

Fig. 2 The duty cycling of master node and sub node n

4. MAC Protocol Performance Evaluation

(1) Throughput and traffic: The throughput is defined as the size of data that is successfully transmitted over a channel per unit time. Assuming that the frame length is fixed and the length is L bits, and the number of frames successfully transmitted per second is n, the throughput can be expressed as nL bps. In general, the throughput is normalized by the channel transmission rate R, and the normalized throughput is represented by S, that is $S=nL/R$.

Similarly, the traffic (load G) is defined as the ratio of the size of data M to be transmitted per unit time to the channel transmission rate R, that is $G=M/R$.

(2) End-to-end latency: The end-to-end latency consists of the packet queuing latency, transmission latency, channel propagation latency and the packet retransmission delay (if the collision or transmission error occurs).

(3) Energy efficiency: The energy efficiency is defined as the ratio of energy consumption to the size of data transmitted successfully in the simulation time.

5. Simulation and Results

In this paper, we discuss the performance of improved protocol ASSTDMA, CSMA/CA and Slotted-FAMA in the star network from three aspects of throughput, end-to-end latency and energy efficiency.

In a circular area with a radius of 1km, 10 sub nodes are uniformly distributed and the master node at the center of the circle. The underwater acoustic velocity is set to 1500 m/s, modulation mode is OFDM, the data frame size is 1115 bits and symbol length is 232 ms.

The throughput of ASSTDMA, CSMA/CA and Slotted-FAMA is illustrated in Figure 3. With the increase of the traffic, the throughput of the three protocols reaches the limit and remains stable. Owning to the high channel utilization, the throughput of ASSTDMA is almost two times that of Slotted-FAMA. The CSMA/CA protocol has the lowest channel utilization, due to the high collision probability.

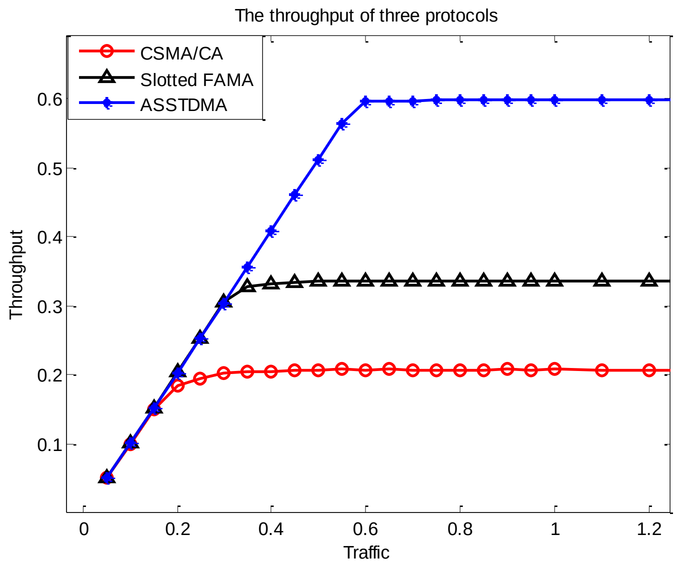

Fig. 3 The throughput of ASSTDMA, CSMA/CA and Slotted-FAMA

The end-to-end latency of three protocols is illustrated in Figure 4. The ASSTDMA has the lowest latency, it benefits from the low protocol overhead. In contrast, the random access and handshaking protocols have the characteristic of good flexibility and low efficiency in underwater acoustic channel. When the traffic increases beyond the throughput limit, the latency increases rapidly. This is caused by the increasing packet queuing and packet retransmission latency.

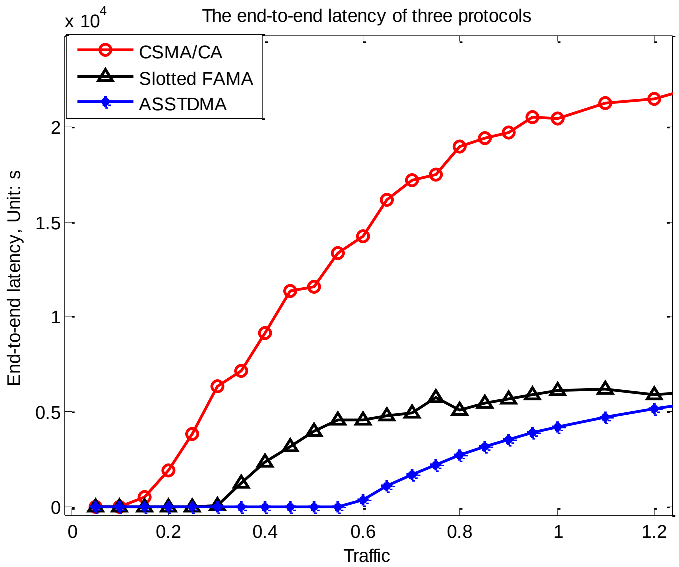

Fig. 4 The end-to-end latency of ASSTDMA, CSMA/CA and Slotted-FAMA

The energy efficiency of three protocols is illustrated in Figure 5. When the traffic is small, the efficiency of three protocols is low due to the standby energy consumption. After the traffic increases beyond the throughput limit, we can observe the ASSTDMA has the best performance, and the Slotted-FAMA and CSMA/CA are inefficient relatively. This is caused by the handshaking and retransmission energy consumption. In contrast, the ASSTDMA specifies that the nodes transmit in corresponding slots and sleep in the idle time.

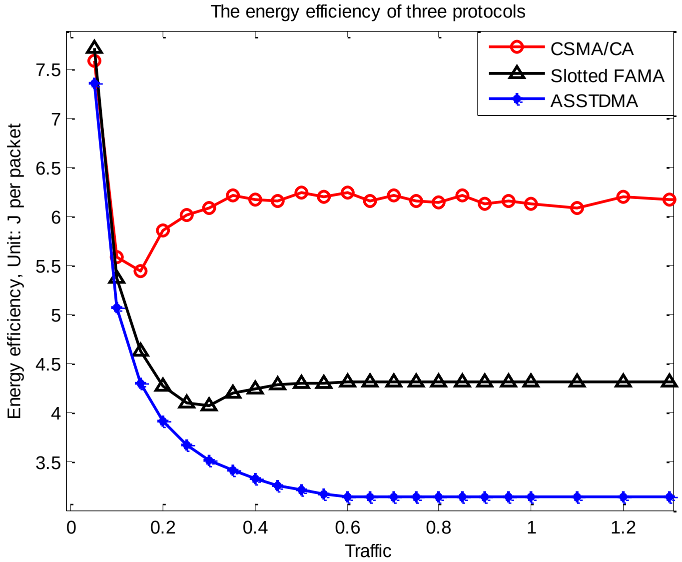

Fig. 5 The energy efficiency of ASSTDMA, CSMA/CA and Slotted-FAMA

6. Summary

In the paper, we present the ASSTDMA underwater acoustic MAC protocol and discuss the comparison among three protocols. The simulation results show the improved protocol has optimized the time synchronization problem. The ASSTDMA protocol uses the high latency characteristics of the underwater acoustic channel through slots allocation and makes it possible for sub nodes to transmit data simultaneously. Meanwhile, the ASSTDMA has a low and stable end-to-to latency which makes it more suitable for the environment monitoring and the information collection.

There are still many problems to be considered in the UWSN MAC protocols, such as underwater mobile nodes access, multi-hop nodes access, fairness of protocol and etc. It is worth proposing different improved MAC protocols for various application environments in the future research.

References

[1] Guo Zhongwen, Luo Hanjiang, Hong Feng, Yang Meng, Ni Mingxuan. Research progress of Underwater Wireless Sensor Networks [J]. Computer research and development. Vol. 47 (2010) No. 3, p. 377-389.

[2] Wang Jing, Chen Jianfeng, Zhang Lijie, Huang Jianguo. Underwater wireless sensor network [J]. Acoustic technology. Vol. 28 (2009) No. 1, p. 89-95.

[3] G. Ranjani, G. Sadashivappa. Characterization of underwater acoustic channels[C]. 2015 International Conference on Applied and Theoretical Computing and Communication Technology (iCATccT). Davangere, 2015, p. 523-528.

[4] M. Stojanovic, J. Preisig. Underwater acoustic communication channels: Propagation models and statistical characterization [J]. IEEE Communications Magazine. Vol. 47 (2009) No. 1, p. 84-89.

[5] Y. Noh, S. Shin. Survey on MAC protocols in Underwater Acoustic Sensor Networks [C]. Communications and Information Technologies (ISCIT), 2014 14th International Symposium. Incheon, 2014, p. 80-84.

[6] K. Chen, M. Ma, E. Cheng, F. Yuan, W. Su. A Survey on MAC Protocols for Underwater Wireless Sensor Networks [J]. IEEE Communications Surveys & Tutorials. Vol. 16 (2014) No. 3, p. 1433-1447.

[7] M. Molins, M. Stojanovic. Slotted FAMA: a MAC protocol for underwater acoustic networks [C]. OCEANS 2006 - Asia Pacific. Singapore, 2006, p. 1-7.

[8] R. Diamant, L. Lampe. Spatial Reuse Time-Division Multiple Access for Broadcast Ad Hoc Underwater Acoustic Communication Networks [J]. IEEE Journal of Oceanic Engineering. Vol. 36 (2011) No. 2, p. 172-185.
[9] Zhang Jiarong, Qiao Gang. Time division multiplexing in underwater acoustic communication network based on relative clock [J]. Journal of Harbin Engineering University. Vol. 35 (2014) No.1, p. 109-114.
[10] Wu Yun: Research on MAC protocol for underwater acoustic sensor networks based on time division (Master, South China University of Technology, China 2011). p. 27.