A MACA-based MAC protocol for Underwater Acoustic Sensor Networks

Wen Lin, En Cheng, Fei Yuan
The key laboratory of underwater acoustic communication and marine information technology (Xiamen University), Ministry of education, China P.R
Xiamen, China P.R
Email: linwen21@163.com

***Abstract*—The medium access control (MAC) protocol design of underwater acoustic sensor networks (UWASNs) faces many challenges: the power limitation at nodes, long propagation delay, low data rates, etc. These challenges of underwater acoustic channels result in the unsuitable usage of terrestrial networks MAC protocol in UWASNs. Moreover, the long propagation delay causes a serious problem for the MAC protocol. In this paper, we propose a new MACA-based MAC protocol with delay tolerant (MACA-DT). It is shown that by using adaptive silent time and simultaneous handshake technique, MACA-DT protocol can improve the channel utilization and alleviate the long end-to-end delay. Simulation results show that our protocol can significantly improves the network throughput and decreases the end-to-end delay when compared with traditional MACA protocols.**

***Index Terms*—Underwater Acoustic Sensor Networks, MACA protocol, Medium Access Control**

I. Introduction and Related Work

The desire to conquer the ocean of human beings becomes more realistic with the development of Underwater Acoustic Sensor Networks (UWASNs). UWASNs can be applied to oceanographic data collection, pollution monitoring, offshore exploration, disaster prevention, assisted navigation, and tactical surveillance applications [1].

Equipped with networked underwater devices is expensive, so it would be desired to operate in the most efficient mode during the longest time. This calls for the design of efficient communication schemes and protocols to offer high data transport capability and good energy efficiency. The efficient design of MAC protocols is one of the hottest issues for UWASNs.

The design of a MAC protocol is challenging for the operation of energy-limited sensor nodes in UWASNs due to energy limitations, long propagation delays, and low data rates and so on. All these factors play an important role on control algorithms of MAC protocols.

The propagation speed of sound in underwater is about 1500m/s. Therefore, propagation delay in underwater channels is five orders of magnitude higher than that in radio frequency (RF) terrestrial channels, and extremely variety that depends on temperature, salinity, and depth, while propagation delay is negligible for short-range RF. Long propagation delay is the main character of UWASNs [2], and this has profound implications on localization and time synchronization.

Roughly, UWASNs MAC protocols can be categorized into two classes: contention-free and contention-based. Contention-free protocols include FDMA, CDMA, and TDMA, where communication channels are separated in frequency, code, and time domain respectively. Because of the severe limitation and highly dependency on distance between two communicating nodes of the available bandwidth, FDMA scheme is not suitable for UWASNs. Other researchers concern CDMA and TDMA protocols for UWASNs, but some inherent problems of these methods still exist in UWASNs, such as the synchronization problem in TDMA and the near-far problem in CDMA. Thus, the feasibility of these protocols in UWASNs is unclear [3] [4] [5].

Various contention-based protocols have been proposed for UWASNs. The first class of contention-based MAC protocols in a shared wireless medium is ALOHA protocols, which have been the basis of many MAC protocols [6] [7].

Nitthita, et al. proposed two Aloha-based protocols, namely, ALOHA with collision avoidance (Aloha-CA) and ALOHA with advance notification (Aloha-AN) [8]. These two protocols utilize the information obtained from overheard packets to calculate the busy durations of neighboring nodes and avoid collisions accordingly. Affan Syed,et al. simple analyzed of the slotted ALOHA protocol in UWASNs and concluded that slotted ALOHA protocol degrades to pure ALOHA protocol under high latency [9].

Later protocols, such as carrier sense multiple accesses (CSMA), achieved better performance than ALOHA protocol in RF network [10]. However, CSMA becomes very expensive in UWASNs due to the large propagation delay. As shown by Kleinrock and Tobagi [11].

Handshaking-based protocols are also representative contention-based schemes such as Slotted Floor Acquisition Multiple Access (S-FAMA) which was

Manuscript received Aguest 1, 2010; revised January 4, 2011; accepted January 31, 2011.

doi:10.4304/jcm.6.2.179-184

proposed by Molins and Stojanovic [12]. Although the S-FAMA protocol achieves collision avoidance for data packets, the lengthened time slot degrades the throughput performance. To overcome the low throughput, another handshaking protocol named multiple access collision avoidance with packet train for multiple neighbors (MACA-MN) was proposed by Nitthita, et al [13]. Guo et al. introduced the propagation-delay-tolerant collision avoidance protocol (PCAP) in [14]. But it requires clock synchronization among all the neighboring nodes. Hai et al. [15] proposed multiple access collision avoidance protocol for underwater (MACAU) which is based on MACA protocol. MACAU protocol is an adaptation of terrestrial MACA protocol for multi-hop UWASNs. Three aspects of the MACA protocol are improved, namely, the state transition rules, the packet forwarding strategy, and the bakeoff algorithm.

The protocols above which employ handshaking approach inevitably amplify the effect of long propagation delay, which restricts the throughput and the end-to-end delay. In this paper, we propose an asynchronous random access MAC protocol based MACA protocol, which is called MACA-DT (MACA for Delay Tolerant) protocol. The protocol utilizes a handshaking-based approach in order to avoid collisions and alleviate the hidden terminal problem in multi-hop UWASNs. In addition, the protocol can overcome the low throughput and the long end-to-end delay problems of typical handshaking-based protocols by using adaptive silent time and simultaneous handshake technique.

The rest of this paper is organized as follow. In section 2, we proposed a new MAC protocol based on MACA protocol. In section 3, the simulations are carried out, and further discussions are provided. Finally we give our conclusions in section 4.

II. MACA-DT Protocol Design

This section describes MACA-DT protocol in detail. We first give an overview of our protocol, and then introduce how to detect propagation delay in initialization phase. After that we present the key techniques it employs: adaptive silent time and simultaneous handshake technique. At last, we discuss how the protocol to effectively reduces the end-to-end delay and improves the throughput. Table 1 shows the notations that will be used.

A. Protocol Overview

Our protocol has two phases: initialization phase and transmission phase. The first phase is used to detect propagation delay between nodes and all of their neighbors. When we finish the first phase, we can operation our protocol in the second phase.

In second phase, we use three way handshakes similarly to the MACA protocol. A node who wants to transmit a data packet will first use a handshake to its intended neighbor by transmitting a request-to-send (RTS) packet. When an intended receiver hears the RTS packet, it will respond with a clear-to-send (CTS) packet immediately, provided that it is currently not involved in a handshake with another node, and is also not required to remain silent. When a no intended receiver hears the RTS packet (xRTS), it will be in a silent state, and sets its silent timer to $T_{silent\text{-}rts}$, similarly, when a no intended receiver hears the CTS packet (xCTS), it will be in a silent state, also set their silent timers to $T_{silent\text{-}cts}$. Some traditional MACA protocols (MACA, MACAU), as shown in Fig.1, set their silent timer to $2T_{max}+T_{data}$ (when receive an xCTS packet) or $2T_{max}+T_{CTS}$ (when receive an xRTS packet). Due to the slow propagation of sound under water, the silent time of traditional MACA is too long for UWASNs. Compare to the traditional MACA who uses the fixed silent time, we use the adaptive silent time to minimize the silent time.

TABLE I.
NOTATIONS USED FOR EXPLAINING THE PROTOCOL

T_{xy}	Propagation delay between node x and node y, T_{xy}=T_{yx}
T_{tx}	Propagation delay between transfer node and node x
T_{tr}	Propagation delay between transfer node and receiver node
$T_{silent\text{-}rts,x}$	The silent time of the node x receives an xRTS packet
$T_{silent\text{-}cts,x}$	The silent time of the node x receives an xCTS packet
xRTS	An RTS packet that intended for another node
xCTS	A CTS packet that intended for another node
T_{data}	Transmission time of each fixed-length DATA packet
T_{cts}	Transmission time of each fixed-length CTS packet
T_{rts}	Transmission time of each fixed-length RTS packet
T_{max}	Maximum propagation delay
$T_{measure}$	The time that the measure packet was sent
T_{ack}	The time that the ACK packet was received

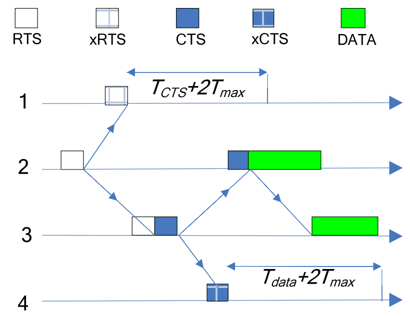

Figure 1. Silent time of traditional MACA protocols.

For conventional MACA protocols, after transmitting an RTS packet, the node keeps silent and waits for a CTS packet replied from the destination. Because of long propagation delay in UWASNs, conventional MACA protocols are inefficient. In our protocol, we utilize simultaneous handshake technique. It allows a sender to perform other actions during the long wait between the RTS packet and the CTS packet (a similar idea is made by Gao et al [14]).

Similar to MACA protocols, when a source node does not receive returned CTS packet in response to its previous RTS packet, the source node shall schedule a packet retransmission using binary exponential back off (BEB) algorithm. MACA-DT protocol also uses BEB algorithm.

B. Initialization Phase

In initialization phase, we use a handshake between the nodes to estimate the propagation delay. As shown in

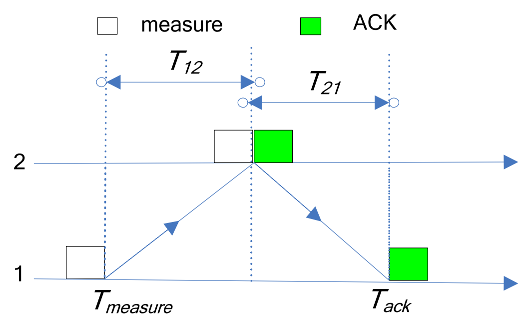

Figure 2. A handshake to estimate the propagation delay.

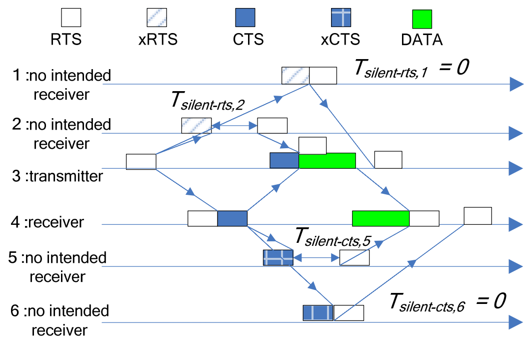

Figure 3. Adaptive silent time

Fig.2, Node 1 wants to estimate the propagation delay to its neighbor Node 2. It sends a measure packet and records when the measure packet was sent out. When the Node 2 receives the measure packet, it immediately returns an acknowledgement character (ACK) packet to Node 1, which then records when the ACK packet was received. Assuming that the propagation delay is symmetric between 1 and 2, Node 1 can estimate the propagation delay from two times: the time that the measure packet was sent and the time that the ACK packet was received:

$$T_{12} = T_{21} = \frac{T_{ack} - T_{measure}}{2} \tag{1}$$

The propagation delay is affected by many factors such as temperature and pressure. In this paper, we assume that the propagation delay is constant in a short time period. We can update these measurements after a short period of time through the RTS/CTS packet exchange in the second phase.

After the initialization phase, each node obtains the propagation delay to all of its neighbors.

C. Adaptive Silent Time

Some traditional MACA protocols use fixed silent time to avoid packet collision. Because of the long propagation delay, the fixed silent time has seriously restricted the throughout. However, long propagation delay also introduces new challenge and a call for new method in the design of MAC protocol.

In contrast to the traditional MACA protocols, MACA-DT uses the adaptive silent time to reduce the silent time of each no intended receiver. When we use adaptive silent time method, the silent time of each no intended node is not fixed. The duration of the adaptive silent time is determined by the propagation delay between the nodes.

The adaptive silent time can be classified as the silent time of no intended receivers who hear an xRTS packet and the silent time of no intended receivers who hear an xCTS packet.

1) Silent time of no intended receivers who hear a xRTS packet: When a no intended receiver hears an xRTS packet, it sets its silent timer to $T_{silent-rts}$ using the following equations:

$$\begin{cases} T_{silent\text{-}rts,x} = 0, & T_{tx} > T_{tr} + 0.5T_{cts} \\ T_{silent\text{-}rts,x} = T_{cts} - 2\times(T_{tx} - T_{tr}), & T_{tr} < T_{tx} < T_{tr} + 0.5T_{cts} \\ T_{silent\text{-}rts,x} = T_{cts} + 2\times(T_{tr} - T_{tx}), & T_{tx} < T_{tr} \end{cases} \tag{2}$$

We calculate the maximum $T_{silent-rts,x}$ of MACA-DT protocol. In this case we assume T_{tr} is a maximum propagation delay such that $T_{tr}=T_{max}$. Equation (2) shows that the maximum adaptive silent time of MACA-DT:

$$\begin{aligned} T_{silent\text{-}rts,x} &= T_{cts} + 2\times(T_{tr} - T_{tx}) = T_{cts} + 2T_{max} - 2T_{tx} \\ &< T_{cts} + 2T_{max} \end{aligned} \tag{3}$$

Hence, the adaptive silent time of MACA-DT protocol is much smaller than traditional MACA protocols.

Let us analyze the minimum $T_{silent-rts,x}$ for MACA-DT protocol. We assume T_{tx} is larger than $T_{tr}+T_{cts}/2$. In this case, the no intended receiver need not to keep silent to prevent interfering the receipt of the CTS packet of the transmit node from the intended receive node.

As shown in Fig.3, node 3 transmits an RTS to node 4, and node 1 hears an xRTS packet from node 3. Node 1 can transmits any packets (in Fig.3, we assume node 1 transmits an RTS packet) immediately instead of keeping silent. When the node 3 receives the RTS packet from node 1, node 3 has already received the CTS packet from node 4.

2) Silent time of no intended receives who hear a xCTS packet: When a no-intended receiver hears an xCTS packet, it sets its silent timer to $T_{silent-cts}$ using the following equations:

$$\begin{cases} T_{silent\text{-}cts,x} = 0, & T_{tx} > T_{tr} + 0.5T_{data} \\ T_{silent\text{-}cts,x} = T_{data} - 2\times(T_{tx} - T_{tr}), & T_{tr} < T_{tx} < T_{tr} + 0.5T_{data} \\ T_{silent\text{-}cts,x} = T_{data} + 2\times(T_{tr} - T_{tx}), & T_{tx} < T_{tr} \end{cases} \tag{4}$$

The adaptive silent time also can reduce the silent time when no intended receivers hear an xCTS packet. Then we also show the minimum $T_{silent-cts}$ for MACA-DT protocol. As shown in Fig.3, node 6 receives an xCTS packet from node 4, it can transmit any packet (in Fig.3, we assume node 1 transmits an RTS packet) immediately instead of keeping silent. When node 4 receives the RTS packet from node 6, node 4 has already received the DATA packet from node 3.

We illustrate the advantage of the adaptive silent time with an example, the example shown in Fig.4. First, let we assume $T_{12}=0.2s$, $T_{23}=0.25s$, $T_{24}=0.6s$, $T_{cts}=0.01s$,

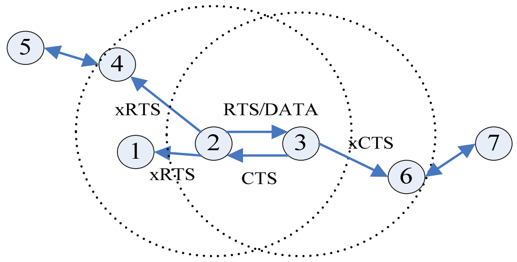

Figure 4. An example underwater network

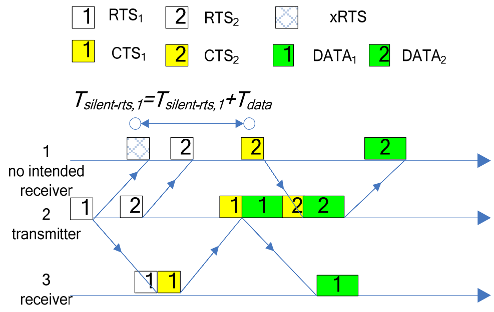

Figure 5. Simultaneous handshake technique

$T_{data}=0.1s$, $T_{36}=0.6s$ and $T_{max}=0.6s$. Our assumption is not necessary to make a MACA-DT protocol be correct, but simplifies our analysis and is consistent with the specifications of UWASNs.

Node 2 has a data packet to send to node 3, it will contend for floor reservation by sending an RTS packet to the destination node 3. Upon receiving the RTS, node 3 immediately replies a CTS packet back to node 2. Node 1 and node 4 overhead an RTS packet that is intended for another node (xRTS) will keep defer in a silent time. If we use traditional MACA protocols, node 1 and node 4 must keep silent for 1.21s. Node 4 can not communicate with node 5 in the silent time. However, if we use adaptive silent time, node 1 only keeps silent for 0.11s and node 4 no need to keep silent. Node 4 can communicate with node 5 without any defer. The same situation as node 4 and node 6, when node 6 overhead an xCTS, it can communicate with node 7 without any defer, because the communication between node 6 and node 7 do not affect the transmission between node 2 and node 3. So we can see the adaptive silent time can decrease the effects of long propagation delay, and improve the throughput of underwater network.

D. Simultaneous Handshake Technique

When a node has transmitted an RTS packet, it waits for the CTS packet replied by the destination. However, since the propagation delay in UWASNs is very high, the typical handshaking-based approach is less efficient. The high propagation delay results in a large transmission time of a handshake (RTS/CTS) between transmit nodes and receive nodes.

In our protocol, we utilize these large gaps which are normally wasted by conventional MACA protocols. For example, node 2 is a transmit node and node 3 is a receive node in Fig.5, when node 2 has transmitted an RTS_1 packet to node 3, it waits for a CTS_1 packet from node 3. Node 1 is a no-intended receiver. It hears the xRTS and sets its silent timer to $S_{ilent.}$ When node 2 waits the CTS_1 packet from node 3, if it wants transmit an RTS_2 packet to node 1, it can start to transit the RTS_2 packet to node 1 immediately. When node 2 receives the CTS_1 from the node 3, it transmits the $DATA_1$ packet to node 3. The node 1 receives the RTS_2 packet from node 2 and immediately resets a new silent time. After the new silent time, it transmits CTS_2 packet to the node 2. Node 2 can receive the CTS_2 packet from node 1, when it has finished transmitting $DATA_1$ packet to the node 3. It can immediately transmit $DATA_2$ packet to node 1 after receiving the CTS_2 packet from node 1.

When node 1 has received the RTS_2 from node 2, node 1 modifies its $T_{silent\text{-}rts,1}$ using the following equation:

$$T_{silent\ -rts,x} = T_{silent\ -rts,x} + T_{data} \tag{5}$$

In summary, our protocol can process multiple handshakes while nodes wait for the CTS packet from receive nodes.

MACA-DT uses simultaneous handshake technique, which are different from MACA: the no-intended node in the silent time disregards any RTS and xRTS packet, but the persistent waiting strategy is abandoned when it receives an RTS packet from the transmit node.

We also use an example to illustrate the advantage of simultaneous handshake technique. As shown in Fig.4, when Node 2 waits for the CTS packet replied by node 3, it has 0.51s of the time gap. Let us assume node 2 have a packet to send to node 1 at this moment, node 2 can send an RTS packet to node 1 within this time gap. Node 1 will modify its silent time to 0.21s after the processing of the RTS from node 2. Here, MACA-DT process two handshakes (node 2 and node 3, node 2 and node 1) while node 2 uses simultaneous handshake technique and it can improve the throughput of network.

III. Simulations And Results

For comparison, we simulate three other MAC protocols: ALOHA, MACA and MACAU. In our simulation, all the protocols are random access MAC protocols that do not require time synchronization.

A. Simulation Settings

We simulate those proposed protocols in OPNET and Multi-hop networks are investigated. The simulated network is a shallow multi-hop communication network type, and the main characters of the network are described as follows. As shown in Fig.6, we simulate a random network where 10 underwater acoustic sensor nodes are uniformly distributed over a 5000 by 5000 m^2 area. The transmission range of every node is set to be 1500m. A sending node randomly chooses another node in the network as the destination. Nodes do not need to synchronize and are half-duplex. Data frames are generated at each node in a network in accordance with a Poisson distribution. The available bandwidth is 10 kHz

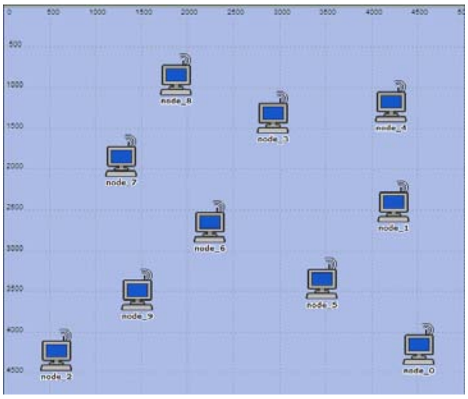

Figure 6. The topology of the simulated network

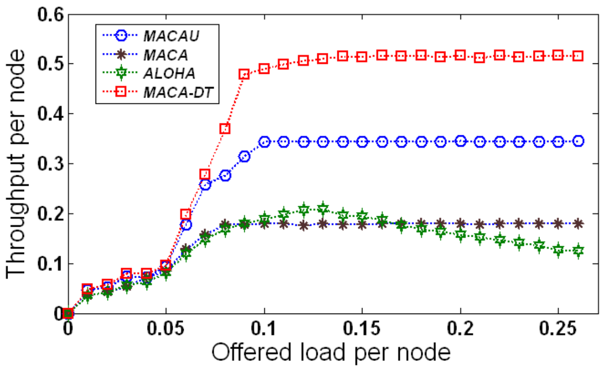

Figure 7. Throughput comparison for MACA-DT, ALOHA, MACA and MACAU

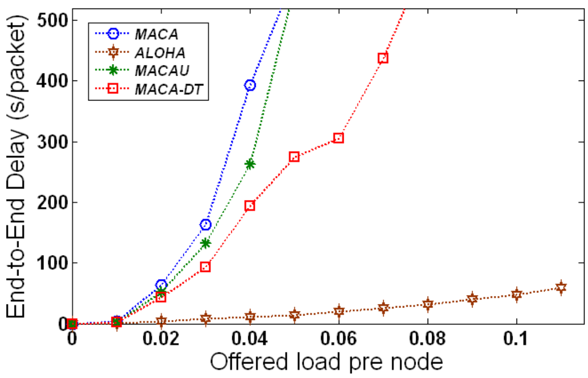

Figure 8. Delay comparison for MACA-DT, ALOHA, MACA and MACAU

and the rate of data transmission is 1000bits/s. The average data packet length is 128 bytes and the control packets (ACK, RTS, CTS and measure) be set 16 bytes. Each simulation runs for 10800 seconds.

The Simulation Kernel of OPNET relies on a 14-stage computational pipeline to evaluate the characteristics of wireless communication when transmissions occur. These can be replaced by user-supplied procedures for other cases. In this paper, for the purpose of modeling of the UWASNs acoustic channel, the procedure of pipeline stages will be modified and the main modification of pipeline stages are shown as follows:

1) The power loss of signal propagation in underwater acoustic channel is set to L_p, which can be calculated in following equation :

$$L_p = D^k \times exp(D \times a(f) / 10) \tag{6}$$

Where D is the distance away from the source, and k is the spreading factor which is usually set to 1 for cylindrical, 1.5 for practical, and 2 for spherical spreading. The simulation value in this paper is 2, because we assume that the signal is transmitted in the form of spherical wave. In the above expression, $a(f)$ is the absorption coefficient. By Thorp's expression [16] in [dB/km],

$$a(f) = \frac{0.11 \times f^2}{1 + f^2} + \frac{44 \times f^2}{4100 + f^2} + 2.75 \times 10^{4} f^2 + 0.03 \tag{7}$$

Where f is the central frequency. For our simulations, we chose parameters as $f = 15$ kHz , because the available channel band 10kHz~20kHz.

2) The propagation speed of acoustic signal in underwater environment is about 1500m/s.

Offered load and Throughput are employed to measure the performance of various protocols in this paper, which are define by (8) and (9) respectively [17].

$$Offered\ load = \frac{\dfrac{total\ data\ packets\ transmitted}{simulation\ time}}{\dfrac{signalling\ rate}{data\ packet\ size}} \tag{8}$$

$$Throughput = \frac{\dfrac{total\ data\ packets\ received}{simulation\ time}}{\dfrac{signalling\ rate}{data\ packet\ size}} \tag{9}$$

B. Simulation Results

The Simulation objective is to study our process on its throughput and end-to-end delay in UWASNs. \As shown in Fig.7, we benchmark our protocol against MACA protocol, MACAU protocol and ALOHA protocol. The figure shows that in all offered load MACA-DT protocol achieved more throughput than other protocols and MACA-DT protocol is able to maintain a stable throughput at high offered load. ALOHA protocol can achieve higher maximum throughput than MACA protocol, but its throughput decreases as the load increases. So ALOHA protocol is no suitable for high load networks. However handshake protocols maintain stable throughput as the offered load increases, at the expense of exchanging small control packets (RTS/CTS) before transmitting DATA packets. The handshake mechanism can avoid collision. MACA-DT protocol uses simultaneous handshake technique to improve throughput, which can process multiple handshakes. Adaptive silent time also improves throughput, because all no-intended nodes only keep shorter silent time than MACA protocol and MACAU protocol when they receive xRTS or xCTS. But with MACA protocol and MACAU protocol, all no-intended nodes must keep longer silent time than MACA-DT protocol when they receive xRTS or xCTS.

Next, we study the end-to-end delay of our protocol. As shown in Fig.8, ALOHA protocol has the lowest end-to-end delay among all four protocols, because it does not need handshake before transmitting DATA packets. We observe that MACA protocol and MACAU protocol have longer end-to-end delay than MACA-DT protocol. By employing adaptive silent time MACA-DT protocol handles the problem and reduces delay well.

IV. Conclusions And Further Work

In this paper, we investigate the MACA protocol in long-delay UWASNs. Based on our analysis, we propose a new MAC protocol based on MACA protocol. Nodes do not need to synchronize and are half-duplex. By employing adaptive silent time and simultaneous handshake technique, our protocol handles the problem of long end-to-end delay well and greatly improves the throughput in the underwater network.

Simulation results clearly show the superiority of MACA-DT protocol over the well-known MACA protocol, MACAU protocol and ALOHA protocol.

In further work, we will simulate MACA-DT protocol by using hardware such as acoustic modern and experiment in the sea. A comparison will be carrying out between simulations and experiments.

Acknowledgment

This work was supported in part by the Key Project of Fujian Province Science and Technology Foundation under Grant 2008H0036, and the Natural Science Foundation of Fujian Province under Grant 2009J05154.

References

[1] Akyildiz.I.F, Pompili.D, Melodia.T, "Underwater acoustic sensor networks: research challenges," *Elsevier's Journal of Ad Hoc Networks*, vol.3, pp.257-279, May 2005

[2] Akyildiz.I.F, Pompili.D, "State-of-the-art in protocol research for underwter acoustic sensor networks," *In WUWNet 2006. Proceedings of the 1st ACM international workshop on Underwater networks,* pp.7-16, 2006

[3] M.Chitre, S.Shahabodeen, M.Stojanovic, "Underwater Acoustic Communciations and Networking: Recent Advances and Future Challenges," *Marine Technology Society Journal*, vol.42, pp.103-116, Spring 2008

[4] Akyildiz.I.F, Pompili.D, Melodia.T, "Challenges for efficient Communication in Underwater Acoustic Sensor Networks," *ACM SIGBED Review*, vol.1, pp.3-8, July 2004.

[5] P.Xie, J.H.Cui, "R-MAC:An Energy-Efficient MAC Protocol for Underwater Sensor Networks," *in Proc. International conference on Wireless Algorithms, Systems and Applications, WASA2007*, pp.187-198, August 2007.

[6] Norman.Abramson, "THE ALOHA SYSTEM: another alternative for computer communications," *AFIPS Joint Computer Conferences*, pp.281-285, Noveember, 1970.

[7] Norman.Abramson, "Development of the ALOHANET," *IEEE Transactions on Information Theory*, vol.31, pp.119-123, March 1985.

[8] N.Chirdchoo, WS.Soh, KC.Chua, "Aloha-Based MAC Protocols with Collision Avoidance for Underwater Acoustic Networks," *In 26th IEEE International Conference on Computer Communications*, pp: 2271-2275, May 2007.

[9] Affan.A.Syed, Wei.Ye, John.Heidemann, Bhaskar Krishnamachari, "Understanding spatio-temporal uncertainty in medium access with ALOHA protocols," *In International Conference on Mobile Computing and Networking,Canada*, Pages: 41 - 48, 2007.

[10] A.S.Tanenbaum, *Computer Networks*, 3rd ed., Englewood Cliffs, NJ:Prentice-Hall. 1996, pp: 243-338.

[11] L.Kleinrock, F.A.Tobagi, "Packet switching in radion channels: Part I-Carrier sense multiple-access modes and their throughput-delay characteristics," *IEEE Trans. Commum*, vol.23, pp: 1400-1416, December 1975.

[12] M.Molins, M.Stojanovic, "Slotted FAMA: A MAC protocol for underwater acoustic networks," *In Proceedings of the IEEE OCEANS'06 Asia Conference*, pp.1-7, May 2006.

[13] Chirdchoo.N, Wee-Seng.Soh, Kee.Chaing.Chua. "MACA-MN: A MACA-Based MAC Protocol for Underwater Acoustic Networks with Packet Train for Multiple Neighbors," *In Vehicular Technology Conference, 2008. VTC Spring 2008. IEEE*, pp: 46-50, May 2008.

[14] Xiaoxing Guo Frater.M.R, Ryan.M.J. "Design of a Propagation-Delay-Tolerant MAC Protocol for Underwater Acoustic Sensor Networks," *IEEE Journal of Oceanic Engineering*, vol.34, pp: 170-180, April 2009.

[15] Hai-Heng.Ng, Wee-Seng.Soh, Motani.M, "MACA-U: A Media Access Protocol for Underwater Acoustic Networks," In *Global Telecommunications Conference, 2008. IEEE GLOBECOM 2008. IEEE*, pp.1-5, December 2008.

[16] L.Berkhovskikh, Y.Lysanov, *Fundamentals of ocean acoustics*, New York: Springer, 1982.

[17] Shahabudeen.S, Chitre.M.A, "Design of networking protocols for shallow water peer-to-peer acoustic networks," *In Oceans 2005 - Europe*, vol.1, pp.628-633, June 2005.

Wen Lin was born in Fujian, China, in 1984. He received the B.E. degree in Communications Engineering from Jimei University, Xiamen China, in 2006, and the M.E. degree in Single Processing from the Communication Engineering Department of Xiamen University, Xiamen, China, in 2009. Currently, he is working towards the Ph.D. degree at the Xiamen University, Xiamen, China.

His interest research area is underwater acoustic sensor networks.

En Cheng received his Ph.D. degree from the Communication Engineering Department of Xiamen University, in 2006. He is a professor of the Communication Engineering Department of Xiamen University and the director of the Key Lab of Underwater Acoustic Communication and Marine Information Technology (Xiamen University), Ministry of Education, Xiamen, China.

His research interests fall in the general area of underwater acoustic communication and networking, spanning from the communication networks, underwater acoustic communication, multi-Media signal processing and communication, video/image quality measurement and embedded system design.

Fei YUAN received his Ph.D. degree from the Communication Engineering Department of Xiamen University, in 2008. He is an assistant professor of the Key Lab of Underwater Acoustic Communication and Marine Information Technology (Xiamen University), Ministry of Education, Xiamen, China.

His research interests fall in the general area of underwater acoustic communication and networking, spanning from the communication networks, underwater acoustic communication, multi-Media signal processing and communication, video/image quality measurement and embedded system design.