Overview of the MAC Protocols for Underwater Acoustic Networks

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Abstract

This paper reviews state-of-the-art of MAC (Medium Access Control) protocols for underwater acoustic networks (UWANs). We first state the underwater channel characteristics and challenges of the MAC protocol design. Then the MAC protocols are classified. The major problems are also discussed in underwater communications. Finally we analyze the protocols and give the research direction in the future.

Keywords

Underwater Acoustic Networks (UWANs); Media Access Control (MAC) protocol; Underwater communication.

1. INTRODUCTION

Many underwater communication devices are deployed in the unreachable underwater world to carry out underwater operations in recent years [1-4]. The installation and maintenance cost of wired equipment is high, and the fixed activity range limits the application of wired communication in an underwater environment. Underwater wireless network technology thus becomes a hot research topic in the past decade. Moreover, the medium access control (MAC) protocol is one of the most critical parts of underwater wireless networks. However, the difference of the underwater communication environment, such as the signals attenuation, long propagation delay and the limited bandwidth transmission resources, let MAC protocol designs in underwater acoustic networks face many new challenges. We first describe the underwater acoustic environment, which includes of the problem and the challenge in designing the protocols. Then we discuss several types of MAC protocols according to the protocol use multiplexing techniques or hybrid MAC. A comprehensive discussion on the significant problems and investigation is given in the remainder of the paper.

2. PROPERTIES

The underwater acoustic network is composed of a large number of nodes deployed underwater. The underwater nodes can collect, transmit and exchange data through an underwater communication modem, and after several hops of transmission, the messages are sent to the water surface stations. The underwater nodes collect the information and then transmit them to water surface, which can extend the land communication range.

2.1. Characteristics of the Underwater Acoustic Channels

The underwater acoustic channel is considered one of the most extraordinary and complex communication media. Due to the particularity of underwater channels, the following channel characteristics should be taken into consideration when designing underwater communication protocols.

1) Large propagation delay. The acoustic velocity is dynamic due to the temperature, salinity and pressure of seawater. The underwater acoustic signal travels at a low speed of about

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1500m/s, which is five orders of magnitude slower than the terrestrial radio signal. The delay caused by underwater transmission can lead to signal distortion, and the mobile transmission caused by wave flow and tide can produce an extreme Doppler effect.

2) Narrow available bandwidth. The available channel bandwidth for acoustics is limited, which is about 5kHz. The bandwidth of the acoustic channel depends on the transmission distance. Within a certain distance, the bandwidth and power of the acoustic channel depend on the signal-to-noise ratio (SNR), sound path loss parameters, and environmental noise of the target node. At large distances, bandwidth is severely limited. For example, only 1kHz of bandwidth is available at 100km. The narrow bandwidth of the underwater acoustic channel means that efficient bandwidth modulation is required when the bandwidth exceeding 1b/s/Hz is achieved on the channel. When the distance between the source node and the destination node is too long, the multi-hop network structure can be considered to transmit at a higher bit rate to reduce the delayed loss and the total power consumption.

3) Time-varying multi-path channels. The speed of sound changes with the location and depth of the nodes. The multi-path effect exists when sound travels underwater. The multi-path propagation effect is caused by the refraction of sound signals in the water or reflected by the water's surface, bottom, and any objects. Signals from the source node take different paths to the destination node. The target node will observe multiple signal arrivals and receive multiple delayed signal components. Horizontal channels may have very long multi-path propagation, and acoustic signals will degrade seriously when the propagation distance is too long. Time-varying multi-path channels affect signal processing, and it also determines signal throughput and communication system performance. Underwater links are greatly affected by the spatial variability of underwater acoustic channels, which will change the channel's physical characteristics.

4) Complicated channel noise. The noise of the underwater acoustic channel includes the ambient noise and the noise of a specific scene. There is always environmental noise in the quiet deep sea. The environmental noise comes from waves, or rain. Most of the environmental noise can be considered as continuous and regular Gaussian noise. Site-specific noise only happens in certain situations, such as animal calls and ship movements. Underwater noise is the main factor that determines available bandwidth, propagation range and signal-to-noise ratio.

2.2. Problems and Challenges of UWANs MAC Protocols Design

According to the characteristics of the underwater acoustic channels. The following factors must be taken into consideration when designing underwater MAC protocol.

1) Synchronization. Due to the Doppler effect, frequency attenuation, multipath propagation, and slow signal propagation speed, it is difficult to realize a precise synchronization (SYN) in the underwater network. However, some UWANs protocols such as scheduling rely on relative time synchronization to make effective operations in a concise time scale.

2) Energy consumption. Underwater nodes are usually battery-powered, so that energy consumption must be considered when designing underwater communication protocols. It is crucial for fixed nodes installed on the seabed, where replacing the batteries or redeploying the nodes is costly. Maintaining the overall life of the network is a crucial factor, so it is essential to design an efficient media access protocol to save energy.

3) Node dynamics. When a node in the underwater network runs out of energy or a new node joins the network, the network structure will change. When designing the MAC protocol, it is necessary to consider the network expansibility to adapt to the new network topology.

4) Fairness. Due to the non-negligibility of the spatial and temporal uncertainty in underwater communication, the source nodes far from the destination nodes are severed much later. Thus, the closer nodes have more opportunities to access the channel.

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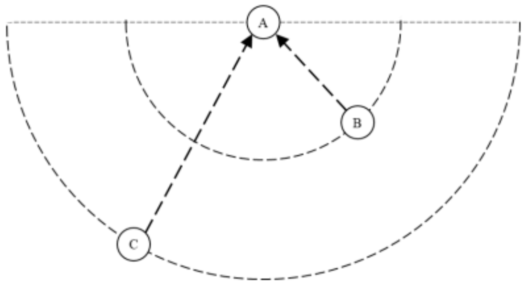

Figure 1. Influence of near and far effect in underwater MAC protocol

5) Near and far effect. The signals received from a sender near the receiver are stronger than those from other senders who are located farther, which will lead to near and far effect. For example, Figure. 1 shows that the distance between node C and node A is longer than the distance between node B and node A. When node C sends a signal to A, the signal sent by node B is considered to be interference.

6) Hidden and exposed terminal problem. Long propagation delays may cause hidden and exposed terminals in underwater communication, as shown in Figure. 2 and Figure. 3.

a) Hidden terminal. When two nodes far away from each other transmit data to the same node, they don't know each other's transmission which may result in collision at target node. As shown in Figure. 2, node A needs to transmit to node B, but node A cannot detect the transmission status of any node within the dashed line when sensing the channel. It results that node A cannot know the transmission of node C, which may cause collision at the target node B. The hidden terminal problems exist in multi-hop and multi-channel underwater environment.

b) Exposure terminal. Two nodes close to each other simultaneously listen to each other to transmit data, and one sender is outside the interference range of the transmitting receiver. As shown in Figure. 3, node A sends control information to node B, while node D transmits data to node C. In terms of chronological sequence, node D sends control information before node A. Node B enters the retreat period after hearing the reply control information of node C, and all node transmissions centered on node C will prevent the data transmission of node A, even though no interference exists.

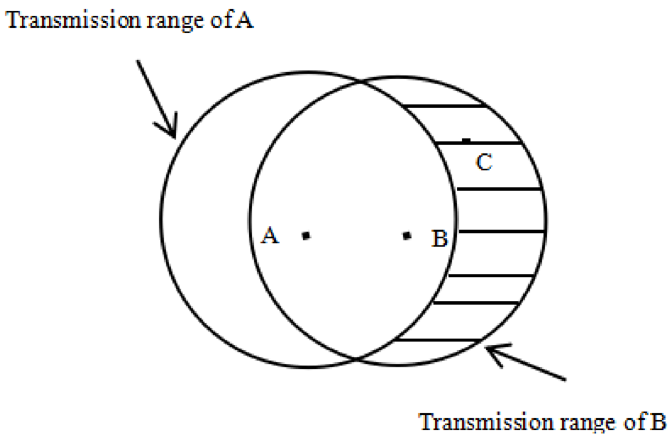

Figure 2. Hidden terminal problem

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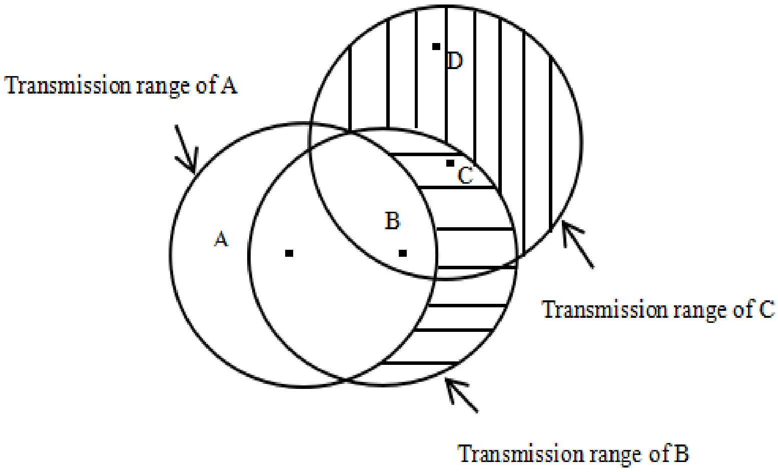

Figure 3. Exposed terminal problem

2.3. Network and Interference Model

The performance of the MAC protocols in underwater communication is highly influenced by the structure of underwater nodes, which can be classified as followed.

a) Star. It is the simplest topology with MAC protocol design. The central node can communicate with nodes in certain range directly.

b) Tree. It is the improvement of star topologies, which can cover a larger area. A parent node is a one-point failure of its sub-tree.

c)Mesh. Mesh is a decentralized network topology in which nodes are interconnected to one another. Each node acts as an AP and provides alternative routes to forward a message from a sending node to its destination node.

There is a source node to coordinate communication between itself and its destination node. This destination node may function as a data sink or just a relay. The structure of the network affects nodes' transmission methods, which are divided as followed,

a) One-hop. The distance between source nodes and destination nodes is one hop without any relay nodes help across the network, which covers a small area.

b) Multi-hop. Unlike the one-hop network transmission mode, each node in the multi-hop network can act as an AP, indicating that nodes in a multi-hop network can help to forward data until the data arrives at the destination node. The following features affect the feasibility of a UWANs multi-hop MAC protocol.

(1) Underwater path loss. Underwater path loss between the underwater source node and the underwater target node over a distance d is given by

$$H(d,\theta) = AS(d,\theta)e^{-\alpha d} \tag{1}$$

Where A is the transmission anomaly coefficient, and α is the absorption coefficient. $S(d,\theta)$ denotes the energy diffusion coefficient. D is the distance between the source node and the target node. θ is the Angle between the direction of the transmitting signal and the horizontal plane.

(2) Physical interference.

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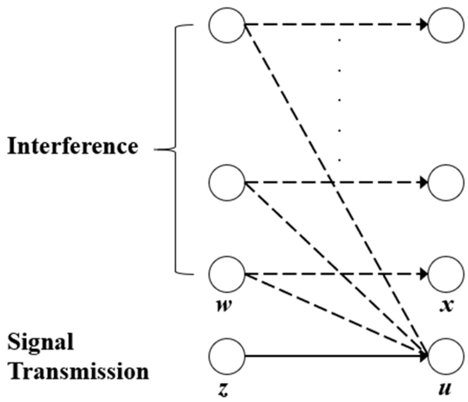

Figure 4. Physical interference model

The physical interference model depends on the receiver's signal-to-noise ratio (SINR). The signal power of the target node is determined by the power of the source node and the path loss between the transmitting node and the receiver node. As shown in Figure. 4, other transmission pairs (such as the data transmitted from the node w to x) cause interference $\sum_{(w,x)\in\xi'} P_{(w,x)}(t')H(d(w,u),\theta')$. According to the physical layer of the network, we can get a threshold γ_{phy} . When the SINR of the target node exceeds the threshold, the signal can be successfully demodulated. When the underwater ambient noise is N_s, the physical interference model is expressed as,

$$SINR = \frac{P_{(z,u)}(t)H(d(z,u),\theta)}{N_s + \sum_{(w,z)\in\xi'} P(w,x)(t')H(d(w,x),\theta')} \geq \gamma_{phy} \tag{2}$$

Due to the physical interference and the need of not exceeding threshold value, collision will happen if the SINR of two simultaneous signals exceeds the threshold value, as shown in Figure. 4.

(3) Protocol interference.

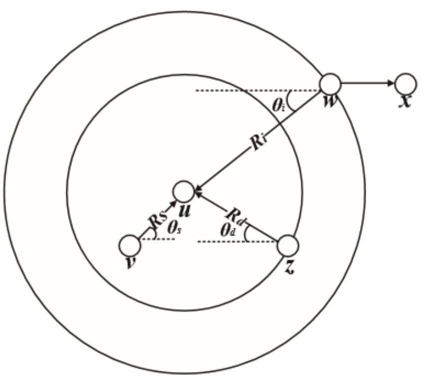

Figure 5. Physical interference model

As shown in Figure. 5, the transmission of each node is limited by range R_d and the larger interference range R_i [5], which is determined by the transmission power. The transmission range is the maximum distance between the target node u and the source node z , at which the received data can be correctly decoded by the target node u . The interference range is the maximum distance between another node w and the target node u. Node w is within the interference range of node u,so that they can hear each other's transmission. The data sent by node w cannot be demodulated at node u, so node w interferes with the transmission between node v and node u [6]. Since the successful reception depends on the signal-to-noise ratio of the destination nodes and underwater path loss, the transmission range R_d and the interference range R_i can be expressed as,

$$\frac{P_{(z,u)}(t)H(R_d,\theta_d)}{N_s}=\gamma_{phy} \tag{3}$$

$$\frac{P_{(v,u)}(t)H(R_s,\theta_s)}{N_s+P_{(w,x)}(t)H(R_i,\theta_i)}=\gamma_{phy} \tag{4}$$

Where $P(w,x)$ is the transmitted power of w. The above equation is the implicit expression of the transmission range R_d and the interference range R_i.

3. CONTENTION-FREE UWANS MAC PROTOCOLS

Contention-free MAC protocols is restricted by the point coordinator who schedules the transmission based on some rules. In this section, we review some contention-free UWANs MAC protocols based on three well known multiple access techniques including of FDMA, TDMA and CDMA. A brief analysis is given at the end of the section.

3.1. FDMA

NOGO-MAC (Node Grouped OFDMA MAC) [7] offers a one-hop energy-efficient MAC protocol, whose nodes are grouped by the distance to the sink node. It allocates each group a specific frequency band to reduce the overall transmission power consumption, and the closer groups have higher frequency. The sink node allocates the subcarrier based on the information exchange. The adaptive-OFDMA system [8] uses an optimal subcarrier selection approach based on emitting the minimum possible transmit power to maintain the available connection. Before transmission, each node will send a short pilot message to reserve to use this communicating subcarrier. In addition, adaptive-OFDMA offers three modes of operation to optimize transmission energy. UW-OFDMAC (Underwater Orthogonal Frequency Division Multiple Access Control) [9] is a transmitter-based OFDMA scheme. A notification packet (NP) is sent to access the channel before transmission. The number of subcarriers for each user depends on the receiver location and motion. The allocation is affected by the accuracy of distance measurement.

3.2. TDMA

Conventional TDMA system in which time is slotted and time slots are organized into frames. Each time slot is assigned to a specific user during subsets of nodes transmit. Thus packets will be sent without collisions. Due to its simplicity and flexibility, TDMA is an available technique applied in UWANs. A TDMA-based MAC Protocol in Underwater Networks is investigated in this section. TDMA-based protocols, such as ST-MAC [10] and STUMP [11], are typical contention-free MAC protocols for UWANs. To get a scalable collision-free packet, STDMA [12] fixes connectivity and interference patterns, which leads to fewer application scenarios. AMPDT [13], based on TDMA, changes the slot length according to dynamic traffic to improve channel utilization. TDA-MAC [14] allows a TDMA-like slotted packet reception at the gateway without

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the need for local synchronization to a global clock. LTDA-MAC (Linear Transmit Delay Allocation MAC) [15] protocol extends the work on TDA-MAC and optimize the packet schedule. It enables unsynchronized packet scheduling in linear transmission structure with taking into account the propagation delays and connectivity pattern.

3.3. CDMA

CDMA make multiple users access AP at the same time, which improves the spectrum efficiency. Each user is assigned unique pseudo-noise (PN) codes that are used for spreading the user messages. Therefore, the receivers can distinguish the correct signals from the noise. [16] proposes a CDMA protocol without any signaling procedure related to channel access and power control. DSSS-CDMA [17] uses filters that can collect the transmitted energy spread over multiple paths to alleviate the effect of multipath at the receiver. At the same time, it allows receivers to distinguish signals simultaneously transmitted in the same frequency band from multiple devices. In FH-CDMA [18], each user can change the central frequency of its modulated signal. The frequency of each user is different at any time within a time interval corresponding to one PN sequence period.

3.4. Analysis

We have reviewed the contention-free MAC protocols based on three primary access medium techniques. The main advantage of UWANs MAC protocols based on contention-free schemes is simplifying MAC protocol design because they have their dedicated resource and may reduce collision problems in high traffic. FDMA uses the signal separation technique in the frequency domain. The FDMA-based protocols and their improvements mainly face the design challenges of limited bandwidth. Typically, the UWA channel exhibits a large Doppler effect that requires guard frequency bands between users, leading to low efficiency and little flexibility. TDMA is much more flexible, but TDMA and slotted-based MAC protocols relys on precise SYN, it is an important issue to balance the collision minimization and channel utilization maximization. CDMA has the advantage of not requiring slot synchronization and more robust to the multipath problem at the price of a bandwidth expansion while CDMA technique introduces the near-far problem and high system complexity, which increases the latency and energy consumption. Contention-free MAC protocols face more severe effect of the near-far effect.

4. CONTENTION-BASED UWANS MAC PROTOCOLS

Nowadays, the efforts to design MAC Protocols for UWANs focus on less energy waste and the increasing utilization of the communication channel. The nodes in contention-based MAC protocols compete for accessing a shared channel without collision. It shows that contention-based MAC protocols may be more flexible and efficient than contention-free MAC protocols. This section reviews the UWANs MAC protocols based on contention.

4.1. ALOHA

The simplest of these protocols is the ALOHA protocol or its enhancements. If a node in ALOHA protocol have data ready to send, it will send without controlling. [19] use the global time synchronization, the nodes in the network can transmit data at the beginning of the time slot. The ALOHA-CA [20] protocol requires that a packet has a header segment and a data segment. It assumes that the knowledge of channel state information between node pairs by listening for packets transmitted. ALOHA-AN [20] protocol can avoid conflicts by sending short notification packets (including source node and target node) before actual data transmission to make neighbouring nodes temporarily delay data transmission. Both protocols reduce data conflicts and improve network throughput compared to the pure ALOHA protocol. However, both protocols require nodes to maintain their tables to monitor neighbouring nodes. The

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ALOHA-RB [21] protocol assumes that the expected number of arrival nodes and the maximum propagation delay are known.

Contention window (CW) is typical settings in protocols to reduce collision. [22] increases the CW randomness to reduce collision. It divided it entire CW into several segments. After a collision happens, the node selects the next segment to get a CW randomly. Therefore, the waste of transmitting power in conflict is much smaller than pure ALOHA protocols. ALOHA-CS [23] is an ALOHA protocol with carrier sensing technique that does not send any new packets as long as the channel is active. It also has a contention window size between two and five times the maximum propagation delay. When the channel is detected to be idle, data will be sent. If there is a conflict, it will enter the backoff time and wait for the subsequent transmission. If the first transmission is unsuccessful, the contention window size will increase accordingly.

4.2. CSMA

CSMA is a representative class of contention-based protocols where each node has to sense the channel for channel reservation. If users listen to the channel before the transmission, it will avoid many collisions. In conventional CSMA/CA, each node starts a carrier sensing before transmitting packets. If the channel is idle, the channel will be reserved by handshaking. Any neighbouring node that overhears a packet intended for another node will defer its transmission and set its network allocation vector (NAV) by the information in the received packet [24]. LACC-M [25] proposed a load-adaptive carrier sense multiple access/collision avoidance MAC protocol. Each node can join and leave the network by introducing a broadcast packet (BCT). The transmission relies on the current state of the network load, which is informed by the BCT packet. P-CSMA (physical CSMA) [26] discusses the different long-delays hidden terminal problems with several transmitting nodes and only one receiving node. CSMA–ALOHA [27] adopts a very short channel sensing phase before transmitting a packet. The short sensing serves to avoid a trivial collision. The sensing time is randomized to avoid the synchronization of channel access attempts and repeated collisions. DACAP (Distance Aware Collision Avoidance Protocol) [28] uses handshake to reserve channels for packet transmission. DACAP senses the channel before transmitting an RTS, which is similar to CSMA/CA. If the destination node overheads some other senders while waiting for a data packet, it will send a short warning packet.

4.3. Handshaking Protocols

SFAMA-MM [29] protocol proposes a multi-receive mechanism that allows neighbouring nodes to receive packets simultaneously based on time slot FAMA. This protocol adds a new notification packet to avoid multi-hop network conflicts, which means some transmitting nodes use notification packets to inform their neighbours about the subsequent data transmission sequence. The sending sequence number is specified for each source node in the CTS packets to schedule the transmitting order of the node. Besides, the transmitting nodes will keep silent after data transmission until the receiving node receives all data packets from other nodes and sends ACK packets to all the transmitting nodes.

OPMAC (On-Demand Pipelined MAC) [30] protocol aims to establish a direct pipeline to forward data from the source node to the destination node without a redundant handshake process. The CTS packet broadcast by the relay node contains the response to the previous-hop node and the request message for the next hop. This mechanism significantly reduces the time for the message to arrive. CTS configured by OPMAC requires advance routing information and may conflict with other transports. Based on distributed UWAN-MAC [31], COPESM-MAC [32] uses parallel execution reservation to reduce the control packet switching time.

CUMAC [33] proposed a cooperative MAC protocol to effectively solve multiple covert terminals by using the cooperation between neighbouring nodes for conflict detection. Besides,

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a tone device was also used to solve the congestion of the control channel and further improve the system performance.

CS-MAC (Channel Stealing MAC) [34] postpones the transmission of the control packets for a duration. After overhearing the control packets, the exposed station can exchange the data with the neighours. The duration divides into small slots and lasts long enough to avoid collision.

4.4. Analysis

In this section, we have reviewed MAC protocols based on contention resolution schemes. ALOHA and CSMA can simplify MAC protocol design and apply it to any network topologies, which are typical terrestrial MAC protocols. ALOHA, nodes transmit with their will. CSMA uses a carrier sensing technique before transmission, intending to avoid collision on the channel. In a sparse environment, they are the ideal choices. Handshaking protocols use the message exchange to reserve the channel before the actual data transmission, which can handle the hidden-terminal problem and near-far effect, but delay for packet becomes long in large UWANs due. Handshaking protocols do not work well for extensive transmission range because of the long propagation delays. Contention-based MAC protocols are more likely used in underwater communication while nodes decide when to transmit on a shared channel.

5. HYBRID UWANS MAC PROTOCOLS

The hybrid MAC protocols combine different medium access techniques to achieve specific requirements. Recently, more and more hybrid MAC protocols are presented in underwater communication. In the following, we present some novel hybrid MAC protocols.

[38] proposed a multi-channel protocol that consists of handshaking and TDMA. Handshaking is implemented using the TDMA technique in a dedicated control channel, which can support multiple successful handshakes in a transmission cycle and avoid collision in additional delay costs.

UW-HARQ (Underwater Hybrid Automatic Repeat Request) [39] uses an efficient CDMA scheme with an adaptive Forward Error Correction (FEC) coding with multi-hop to increase channel reuse and reduce packet retransmissions.

In order to avoid collisions and improve energy efficiency, a class of multi-channel MAC for UW-ASNs (MC-UWMAC) [40] is proposed. MC-UWMAC allows multiple data communications and handshaking on the common control channel, which is slotted to coincide.

LBTSA (load-based time slot allocation) [41] consists of TDMA and carrier-sense multiple access with collision avoidance (CSMA/CA) and selects the slot allocation scheme according to the instantaneous network load. However, LBTSA adopts a long slot duration to ignores the impact of the long propagation delay in underwater communication.

[42] combines contention-based and random access MAC protocol for energy effective dynamic scheduling. It uses a variable step size firefly algorithm (VSSFFA) to generate optimal cluster heads and energy-aware clusters. The VSSFFA reduces the cost of locating optimal positions for the head nodes in a cluster. If a node hears the signals in the channel, it will go to sleep mode to avoid collisions and save energy. In addition, EDS-MAC makes lower end-to-end delay and increased throughput by using dynamic slot allocation and efficient clustering techniques.

To summarize, in this section, we discuss a few hybrid MAC protocols to present the state of the art of design of the MAC protocols in UWANs. These protocols combine the strength of the typical terrestrial MAC technique and the characteristics of the underwater communication environment to design efficient protocols. The hybrid MAC protocols still face the complex structure of the underwater topology and algorithmic complexity. A detailed characteristics of

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different UAWNs MAC protocols have been presented in Table 1, in which the current solution of the MAC protocols in UAWNs is based on the contention or contention-free scheme.

Table 1. Characteristics of underwater acoustic networks mac protocols

Scheme		Protocol name/ Reference	Energy Consumption	Network Throughput	Collisions Rate	End-to-end Delay	Channel Utilization	Concurrent Transmissions
Contention-free	FDMA	NOGO-MAC	Low	Medium	Low	Medium	High	Yes
		[8]	High	Medium	Medium	Medium	High	Yes
		UW-OFDMAC	High	High	Medium	Medium	High	Yes
	CDMA	ST-MAC	High	Medium	Low	Medium	High	No
		STUMP	Medium	High	Low	Medium	High	Yes
		STDMA	Medium	High	Low	Medium	Medium	Yes
		LTDA-MAC	Low	Medium	Medium	Low	High	Yes
		AMPDT	High	High	Low	Low	Medium	No
		TDA-MAC	Low	Medium	Medium	Low	Medium	Yes
	CDMA	[16]	High	Medium	Medium	Medium	High	Yes
		DSSS-CDMA	High	High	Medium	High	High	Yes
		FH-CDMA	High	Medium	Low	High	Medium	Yes
Contention-Based	Random Access	S-ALOHA	Medium	Low	Low	Low	Medium	Low
		ALOHA-CS(AN)	Medium	Medium	Low	Medium	Low	No
		ALOHA-RB	Medium	Medium	Low	High	Low	No
		CSMA-ALOHA	Medium	Medium	Medium	High	Low	No
		DACAP	High	Medium	Medium	High	High	Yes
		LACC-M	Medium	High	Medium	Low	Medium	No
	Handshaking	SFAMA-MM	Medium	Medium	Low	High	Low	No
		OPMAC	High	Low	Medium	Low	Low	Yes
		UWAN-MAC	Low	Low	Low	Low	Low	No
		COPESM-MAC	High	Medium	High	Medium	Medium	Yes
		CUMAC	Low	Medium	Low	Medium	High	Np
		CS-MAC	Medium	High	Medium	High	Low	No
		S-FAMA	Medium	Medium	Low	High	Low	No
		R-MAC	Low	Medium	Medium	Medium	High	Yes
		NR-MAC	Low	Medium	Medium	Medium	High	Yes
Hybrid		[38]	High	High	High	Medium	Medium	Yes
		UW-HARQ	High	Low	High	Medium	Medium	Yes
		MC-UWMAC	Low	Medium	Low	High	Medium	No
		LBTSA	Medium	Medium	Medium	Low	Medium	No
		EDS-MAC	Low	Medium	Low	Low	Low	No

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6. CONCLUSION

This paper summarizes the characteristic of underwater acoustic channels such as long propagation delay and synchronization and the challenge of underwater acoustic MAC protocols design. Then we classify the underwater acoustic MAC protocols based on contention-free like FDMA, TDMA, CDMA, or contention resolution schemes like ALOHA, CSMA, handshaking and Hybrid MAC protocols, which use the advantages of several types of MAC protocols. The research shows that underwater MAC protocols based on contention-free can simplify the protocol design, but the protocols have their potential problems, such as setting guard frequency bands between users in FDMA. Many contention-based underwater acoustic MAC protocols are aware of the propagation delay for collision avoidance. However, there are no single MAC protocols considered as an ideal solution for all underwater communication. Furthermore, future research is expected to design a more robust MAC protocol for underwater communication, considering utilizing the propagation delay, synchronization to improve the performance of the MAC protocol.

REFERENCES

[1] J. Preisig: Acoustic Propagation Considerations for Underwater Acoustic Communications Network Development, WUWNet '06 (Los Angeles, CA, USA, Sep. 2006). p. 1-5.

[2] Stojanovic, M: Underwater Acoustic Communication (2015).

[3] Stojanovic, M. and J. Preisig: Underwater Acoustic Communication Channels: Propagation Models and Statistical Characterization, IEEE Communications Magazine, Vol. 47(2009), p.84-89.

[4] Kao, Chien-Chi, Yi-Shan Lin, Geng-De Wu and Chun-Ju Huang: A Comprehensive Study on the Internet of Underwater Things: Applications, Challenges, and Channel Models †, Sensors (Basel, Switzerland) 17 (2017), n. pag.

[5] Gupta, P., & Kumar, P.R: Capacity of Wireless Networks, IEEE Trans. INF. Theory, Vol. 46 (2000), p.388-404.

[6] Fengji Ye, Su Yi and B. Sikdar: Improving Spatial Reuse of IEEE 802.11 Based Ad Hoc Networks, GLOBECOM '03. IEEE Global Telecommunications Conference (San Francisco, Dec. 2003). Vol. 2. p.1013-1017

[7] Cheon, Jinyong and Ho-Shin Cho: A delay-tolerant OFDMA-based MAC protocol for underwater acoustic sensor networks, 2011 IEEE Symposium on Underwater Technology and Workshop on Scientific Use of Submarine Cables and Related Technologies (2011), p.1-4.

[8] Khalil, Issa M., Y. Gadallah, M. Hayajneh and A. Khreishah: An Adaptive OFDMA-Based MAC Protocol for Underwater Acoustic Wireless Sensor Networks, Sensors (Basel, Switzerland,2012), Vol.12, p. 8782 - 8805.

[9] F. Bouabdallah and R. Boutaba: A Distributed OFDMA Medium Acccess Control for Underwater Acoustic Sensors Networks, 2011 IEEE International Conference on Communications (ICC), (2011), p.1-5.

[10] Kredo II, P. Djukic, and P. Mohapatra: Stump: Exploiting position diversity in the staggered tdma underwater mac protocol, IEEE INFOCOM 2009, (2009), p. 2961–2965.

[11] S. Lmai, M. Chitre, C. Laot, and S. Houcke: Throughput-efficient Super-TDMA MAC Transmission Schedules in Ad Hoc Linear Underwater Acoustic Networks, IEEE Journal of Oceanic Engineering, vol. 42(2017) no. 1, p. 156–174.

[12] R. Nelson and L. Kleinrock: Spatial-TDMA: A Collision-free Multihop Channel Access Protocol. IEEE Trans. Commun., vol. 33(1985), no. 9, p. 934-944.

[13] Mei, Haodi, Haiyan Wang, Xiaohong Shen and Weigang Bai: An Adaptive MAC Protocol for Underwater Acoustic Sensor Networks With Dynamic Traffic, OCEANS 2018 MTS/IEEE Charleston (2018), p. 1-4.

[14] Morozs, N., P. Mitchell and Y. Zakharov. TDA-MAC: TDMA Without Clock Synchronization in Underwater Acoustic Networks. IEEE Access 6 (2018), p.1091-1108.

[15] Morozs, N., Mitchell, P., & Zakharov, Y.: Linear TDA-MAC: Unsynchronized Scheduling in Linear Underwater Acoustic Sensor Networks. IEEE Networking Letters, Vol.1(2019), p. 120-123.

[16] Seo, B., Ju-Phil Cho and Ho-Shin Cho: A Signaling-Free Underwater Code Division Multiple Access Scheme. Electronics, Vol.8 (2019), p. 880.

[17] Chen, Yen-Da, Chan-Ying Lien, Sun-Wei Chuang and K. Shih: DSSS: A TDMA-based MAC Protocol with Dynamic Slot Scheduling Strategy for Underwater Acoustic Sensor Networks. OCEANS 2011 IEEE - Spain (2011), p. 1-6.

[18] Ye, Tianyi: Design and Implementation of FH-CDMA Technology for Shallow Sea Underwater Acoustic Network. 2019 2nd International Conference on Information Systems and Computer Aided Education (ICISCAE) (2019), p. 431-435.

[19] S. De, P. Mandal, and S. S. Chakraborty: Characterization of ALOHA in Underwater Wireless Networks. 2010 National Conference On Communications (NCC) (2011), p. 1–5.

[20] Chirdchoo, N. et al: Aloha-Based MAC Protocols with Collision Avoidance for Underwater Acoustic Networks, IEEE INFOCOM 2007 - 26th IEEE International Conference on Computer Communications (2007), p. 2271-2275.

[21] N. Parrish, L. Tracy, S. Roy, P. Arabshahi, and W. L. J. Fox: System Design Considerations for Undersea Networks: Link and Multiple Access Protocols, IEEE Journal on Selected Areas in Communications, Vol. 26(Dec. 2008), No. 9, p. 1720 -- 1730.

[22] N. M. Yao, Z. Peng, M. Zuba, and J.-H. Cui: Improving aloha via backoff tuning in underwater sensor networks. 2011 6th International ICST Conference on Communications and Networking in China (CHINACOM)(Harbin, China, Aug. 2011),2011, p. 1038–1043.

[23] F. Guerra, P. Casari, and M. Zorzi: World Ocean Simulation System (WOSS):A Simulation Tool for Underwater Networks with Realistic Propagation Modeling, WUWNET '09(Berkeley, CA, USA, Nov. 2009), No. 4.

[24] Zheng, Maochun: Directional Received Medium Access Control Protocol for Underwater Sensor Networks, Journal of the Acoustical Society of America, Vol. 141 (2017). P. 3990-3990.

[25] Zhang, Yayuan, Huifang Chen and Wen Xu: A Load-adaptive CSMA/CA MAC Protocol for Mobile Underwater Acoustic Sensor Networks, 2018 10th International Conference on Wireless Communications and Signal Processing (WCSP) (2018), p. 1-7.

[26] Wang, Deqing, Xiaoyi Hu, Fang Xu, H. Chen and Y. Wu: Performance Analysis of P-CSMA for Underwater Acoustic Sensor Networks, 2012 Oceans - Yeosu (2012), p. 1-6.

[27] F. Favaro, S. Azad, P. Casari, and M. Zorzi: Extended abstract: On the performance of unsynchronized distributed MAC protocols in deep water acoustic networks. in Proc. ACM Int. Workshop Underwater Netw. (WUWNet), Seattle, WA, USA, Dec. 2011, Art. no. 17.

[28] B. Peleato and M. Stojanovic: Distance aware collision avoidance pro tocol for ad-hoc underwater acoustic sensor networks," IEEE Commun. Lett., vol. 11, no. 12, pp. 1025–1027, Dec. 2007.

[29] Huang, W. et al: SFAMA-MM: A Slotted Fama Based MAC Protocol for Multi-Hop Underwater Acoustic Networks with A Multiple Reception Mechanism, 37th Chinese Control Conference (CCC) (2018):7315-7321.

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202109_7(9).0006

[30] F. Dou and Z. Peng: On-demand Pipelined MAC for Multi-hop Underwater Wireless Sensor Networks, Proceedings of the 10th International Conference on Underwater Networks & Systems(Arlington, VA, USA, Oct. 2015), Art. no. 26.

[31] M. K. Park and V. Rodoplu: Uwan-MAC: An Energetic-Efficient MAC Protocol for Underwater Acoustic Wireless Sensor Networks, IEEE Journal of Oceanic Engineering, Vol. 32(2007), No. 3, p. 710-720.

[32] Xia, Yiqian et al: COPESM-MAC: A Conquering-Based Medium Access Protocol Using Parallel Reservation and Sleep Mode for Underwater Acoustic Sensor Networks, OCEANS 2019 – Marseille(2019), p. 1-5.

[33] Zhou, R. et al: Handling Triple Hidden Terminal Problems for Multichannel MAC in Long-Delay Sensor Networks, IEEE Transactions on Mobile Computing, Vol. 11 (2010), p. 139-154.

[34] Y.-D. Chen, S.-S. Liu, C. M. Chang, and K.-P. Shih. CS-MAC: A Channel Stealing MAC Protocol for Improving Bandwidth Utilization in Underwater Wireless Acoustic Networks, OCEANS'11 MTS/IEEE KONA(Waikoloa, HI, USA, Sep. 2011), p. 1–5.

[35] Molins, M. and M. Stojanovic: Slotted FAMA: A MAC Protocol for Underwater Acoustic Networks, OCEANS 2006 - Asia Pacific (2006), p. 1-7.

[36] M. Q. Liu, W. K. Huang, L. F. Qian, and S. L. Zhang: An Improved R-MAC Based MAC Protocol for Underwater Acoustic Networks, 2016 IEEE International Conference on Signal Processing, Communications and Computing (ICSPCC) (Hong Kong, Aug. 2016), p. 1–6.

[37] P. Xie and J.-H. Cui: R-MAC: An energy-efficient MAC protocol for underwater sensor networks, International Conference on Wireless Algorithms, Systems and Applications (WASA 2007)(Chicago, IL, USA, Aug. 2007), pp. 187–198.

[38] Zhang, Jun, Hu-Xian Zhi, Yan Xiong and Geng-xin Ning: A Collision-Free Hybrid MAC Protocol Based on Pipeline Parallel Transmission for Distributed Multi-Channel Underwater Acoustic Networks, Electronics, Vol.9 (2020), p. 679.

[39] Mo, H., A. C. Mingir, H. Alhumyani, Y. Albayram and Jun-hong Cui: UW-HARQ: An Underwater Hybrid ARQ Scheme: Design, Implementation and Initial Test. 2012 Oceans (2012), p. 1-5.

[40] Bouabdallah, Fatma, Chaima Zidi, R. Boutaba and A. Mehaoua: Collision Avoidance Energy Efficient Multi-Channel MAC Protocol for UnderWater Acoustic Sensor Networks. IEEE Transactions on Mobile Computing, Vol.18 (2019), p. 2298-2314.

[41] Zhang, Ziwei, Wei Shi, Qiuna Niu, Ying Guo, Jingjing Wang and Hanjiang Luo: A Load-Based Hybrid MAC Protocol for Underwater Wireless Sensor Networks, IEEE Access, Vol.7(2019), p. 104542-104552.

[42] Sundararaj, Vinu, S. Muthukumar and R. Kumar: An optimal cluster formation based energy efficient dynamic scheduling hybrid MAC protocol for heavy traffic load in wireless sensor networks, Comput. Secur, Vol.77 (2018), p. 277-288.