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Review of ALOHA-based MAC Protocols for Underwater Wireless Sensor Networks

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KEYWORDS:
MAC protocols; ALOHA protocol; underwater wireless sensor network

***Abstract*—The aquatic environment has become clearer and more controllable since Underwater Wireless Sensor Networks (UWSNs) intervened to detect them, because underwater wireless sensor networks are efficiently providing and supporting many civilian and military applications, and many have been decomposed and extracted for helping to avoid falling into many problems, causing many physical and economic losses. Media Access Control (MAC) protocol plays a fit role to enhance the performance of the network which helps to quickly accomplish the tasks that are required from the network and without additional cost. Low and limited bandwidth, energy, limited memory, long and variable propagation delay, and high bit error rate are some challenges that face the designing of the MAC protocol for UWSNs. ALOHA protocol is one of the most popular MAC protocols. In this article, we focus on providing a review of the state of art of the most recent developments of ALOHA protocols for UWSNs from recent literature. These protocols are P-ALOHA, S-ALOHA, ALOHA–CS, ALOHA-AN, BUFFERED-ALOHA, SLOTTED-CS-ALOHA, VI-ALOHA, L-ALOHA, ST-SLOTTED-CS-ALOHA, MODIFIED-SLOTTED-ALOHA, SLOTTED-BUFFERING-ALOHA, and BUFFERING_SLOTTED_ALOH. A discussion of the characteristics and restrictions of every ALOHA protocol in addition to explaining comparisons among all these protocols according to different performance metrics is also presented in this paper. The performance metrics used are the average delay, the energy consumption ratio, the number of dropped nodes, and the throughput ratio.**

I. INTRODUCTION

THE discovery of the depths of the seas and oceans has become more pressing than ever due to many applications that can be implemented in the depths of these seas and oceans using wireless sensor networks that help in executing these tasks. Given the importance of these applications recently, there has been considerable interest in research analysis and improvement of UWSNs. The main reason for studying these networks is that they can enhance the ocean reconnoitering and meet the needs of multiple underwater applications [1-4]. UWSNs have protruded to be a master type of system for ocean exploration and vision where underwater sensor networks are used in the detection of underwater oil fields as well as identification of

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subsea network cables. Moreover, it also helps in the exploration of expensive minerals. In addition, Underwater Wireless Acoustic Sensor Networks (UW-ASNs) can also help reduce the pollution phenomenon [5]. For more details about the applications of underwater acoustic sensor networks can be found in [6]. To provide higher throughput in the power efficient manner without additional cost, it is essential to design the MAC protocol for UWSN, because the MAC layer protocol coordinates the access of the nodes to shared wireless media. The MAC protocol lets nodes in the network to share public broadcast channels [7].

UWSN's MAC protocol study is a popular new field. The research did not explore too much in the literature. Unlike Terrestrial Wireless Sensor Networks (TWSNs), which utilized radio waves to transmit data. UWSNs mainly depend on acoustic waves for transmitting data, this poses a huge challenge to the design of an efficient MAC protocol.

Sundry new MAC protocols relied on their media access strategy are studied to emphasize the problems inherited of the physical stratum, which must be considered when designing the protocol of the MAC [8].

Several MAC protocols in UWSNs have been analyzed on the algorithms, the features, and the weakness of every protocol [9]. A lot of challenges, obstacles to the designing of an efficient MAC protocol for UASNs, that including high transmitting loss, low and limited bandwidth, long and variable propagation delay, and Doppler propagation. For that, the all-previous challenges must be considered when designing the protocol of the MAC [10].

Although there are many challenges, there are many implementations that can be utilized in UWSN, including environmental observation, calamity prevention, oil-gas leak finds, and defilement observation [11]. UWSN human observation can help avert person-made and natural calamities, raise the potential for economic growth and conserve maritime life.

The MAC protocol in wireless communications is necessary for allowing nodes to effectively share finite usage resources and let the simultaneous transmission through the common channel [7].

This article differs from other survey articles in that it provides an overall review of the state of the art of the most recent developments of ALOHA protocols for UWSNs from recent literature. The aim of this survey is to help in overcoming the challenges that face the design of the MAC protocol for UWSNs such as Low and limited bandwidth, energy, limited memory, long and variable propagation delay, and high bit error rate. The survey is concentrating on the ALOHA protocol because it is one of the most popular MAC protocols. It provides an essential classification of the protocols in more details along with highlighting the advantages and disadvantages of each.

The structure of our article is arranged as follows. In part II, we generally discussed the major challenges of UWSNs communication compared with TWSNs. In part III, we put forward the challenge of MAC protocols design. While in part IV, we present the basic classifications of MAC protocols for UWSNs. Part V introduces the ALOHA protocol and presents its classifications. Part VI concludes this article. While part VII presents a list of the abbreviations used in this paper.

II. MAJOR CHALLENGES OF THE UWSNS COMMUNICATION

The major objective of UWSN and TWSN is in the end to transfer data among the ends to meet the requirements of the application. In the underwater acoustic environment, the waves of radio decay swiftly. Therefore, the ability of the signal is to travel shortened distances only. Water absorbs the optical (light) signals quickly. At the same time, the optical dispersion resulting from the suspension of particles and plankton has a great impact. Therefore, the optical signal cannot travel very far under harsh conditions [12]. In the other direction, the waves of acoustic are less attenuated. Therefore, these waves can travel longer distances than optical signals and waves of radio [7,13,14]. So, waves of radio are utilized for communication in the TWSN with a constant propagation speed of about $3 * 10^8$ m/s. While in UWSN, the waves of acoustic are used for communication with a variable propagation speed of nearly $15 * 10^2$ m/s [7]. We display the characteristics of each communication method in Table I.

TABLE I
CHARACTERISTICS OF UWSNS COMMUNICATION MODALITIES [7,15,16].

	Waves of Acoustic	**Waves of Radio**	**Waves of optical**
Frequency Band	~Khz	~Mhz	~10^{14}-10^{15} Hz
Bandwidth	~Mhz	~Khz	~10-150 Mhz
Energy Consumption	~28 Db/1 Km/100 Mhz	>0.1 Db/M/Hz	∝ Turbidity
Effective Range	~10 M	~1 M	~10-100 M
propagation Speed (M/S)	~$1.5 * 10^3$	~$3 * 10^8$	~$3 * 10^8$
Antenna Size	~0.1 M	~0.5 M	~0.1 M
Communication range	~Km	~10 m	~10-100 m
Features	Long communication range	Unaffected by noise, non-line of sight, turbidity	Low delay, high data rate, low power consumption
Weakness	Low data rate, high delay high pass loss	Antenna size is large, short connection domain	Line of sight, short connection domain

The sensor node is considered as an active element in both Terrestrial WSNs and UWSNs which is powered with finite batteries. However, compared with TWSN, the power consumption of sending and receiving data in UWSN is higher. High energy consumption will shorten the life of the network. In addition, earth networks power supply is easy to recharge and can utilize solar power and can also be replaced regularly while on the other hand, UWSN power supply cannot be easily recharged and solar power cannot be used [7,10]. Furthermore, it cannot be replaced regularly due to there is a huge number of nodes in the network, and harsh underwater environments, sensor nodes in TWSN usually communicate within a short period distance, while sensor nodes communicate in UWSNs at a long distance. Thus, a higher energy is required in UWSN for communication between scattered nodes. As a result, the network life of UWSNs is shorter as compared to TWSNs. However, compression data, aggregation data, sleep, energy-saving scheduling algorithms and routing protocols can increase the network lifetime of UWSNs [17]. In the table II, we have listed the most important factors to show the main differences among TWSNs and UWSNs. All these factors are the main important parameters in extending the life of the network and improve network performance.

TABLE II [7,18,19]: MAIN DIFFERENCES AMONG CHARACTERISTICS OF TWSNS. AND UWSNS.

Factors	**TWSNs.**	**UWSNs.**
Common connection method	Radio waves	Acoustic waves
Propagation speed	$3 * 10^8$ m/s	$15 * 10^2$ m/s
Data rate	High data rate	Low data rate
bandwidth	High	Low
Energy consumption	Low	High
Noise	Less effect	High effect
Bit Error Rates	Low	High
Propagation delays	Short and stable propagation delays	Long and variables propagation delays

III. CHALLENGES OF THE DESIGN OF MAC PROTOCOLS

Unlike classic networks, Wireless Sensor Networks (WSNs) have their own resources and design limitations especially in underwater networks. Resource limitations that include a limited amount of power, a short connection range, low bandwidth, and limited processing and storage at each node are an essential part of a WSN [7]. So, the MAC protocol is necessary in wireless communications to let nodes to efficiently share finite resources and to let simultaneous transmissions through common channel [20].

In general, underwater acoustic environment introduces new challenges and issues that must be processed while designing a suitable MAC protocol compared to MAC design for terrestrial networks [8,10,21,22].

Some important factors affecting the deterioration of underwater communications in UWSNs are discussed as follows: [10,16]

A. Limited bandwidth

The available bandwidth in TWSN can be close to 928 MHz, while in UWSNs it can be close to 100K Hz. In general, available bandwidth of the underwater acoustic channel relies on the frequency and the range [23]. As a result of the finite frequency used to send data and noise in UWSNs, the throughput is reduced, resulting in a lower sending rate compared with TWSNs. The finite bandwidth of UWSN can cause network crowding, thus increasing delays, data loss rate, and ultimately increasing power consumption. Available bandwidth relies on signal frequency and connection bands [24]. The short connection rang has a higher bandwidth, whereas the long connection range has a lower bandwidth.[25].

B. Long and Variable Propagation Delay

The velocity of sound propagation in underwater is about 1500 m/s [26]. Therefore, the underwater propagation delay is five times greater than the Earth's Radio Frequency (RF) over the terrestrial channels. Due to the high transmission delay in underwater, the data transmission collision is very high [27]. The delay of underwater reproduction is highly variable and relies on the temperature, salinity and depth of the water. Although the propagation delay is negligible for short range radio frequencies, it is essential for underwater connections. It has profound implications for the design of the MAC protocols.

C. Noise

Environmental noise includes man-made noise and ambient noise. Man-made noise mainly references to the noise of machinery such as pumps whereas natural noise references to seismic and biological phenomena that can cause ambient noise. Due to the environmental noise in the control channel, the underwater node connection may be disconnected [15].

D. Power consumption

Underwater acoustic transceivers have an order of magnitude greater transmission capabilities than terrestrial devices with a higher percentage of transmission for receiving power, thus protocols using sound radio become more important in UWSNs [28]. UWSNs have many special characteristics that set it apart from traditional networks. Energy limitation is one example of this [29-31]. Since batteries are power constrained, they cannot be easily recharged.

E. Doppler-spread

Changing the position of the sender or receiver can cause Doppler diffusion. As a result, to the lower velocity of propagation of acoustic waves compared to radio waves. The Doppler propagation of UWSNs will have a much larger number of TWSNs. Authors in [32] showed that the Doppler propagation in a narrow band system can be fixed on the whole bandwidth. As a result of the propagation of Doppler a lower transmission rate may be present and, eventually, severe deterioration in the performance of acoustic communications. When designing an effective MAC protocol for UWSN networks, it is needful to study the initial factors that can degrade the performance of the MAC protocol. Authors in [15] proved that water, temperature, transport band, salinity, and node motion are the most important environmental factors that have a significant impact on underwater communications.

F. Synchronization

Synchronization is a serious challenge in MAC protocol design since the duty cycle work in MAC protocols generally depends on the synchronization time of nodes [8]. Due to the lack of precise synchronization, the duty cycle approach cannot certify the efficient processing of sensor networks by addressing the time uncertainty between sensor nodes. This is due to; the propagation delay factor is so higher and changes periodically from time to time.

G. *Central networks*

Centralized solutions are not applicable over acoustic channels in UWSN [33]. In a centralized network scenario, connection between nodes is carried out through a Centralized station. The main weakness of this configuration is that there is a single point of failure. In addition, as a result for the finite band of an odd modem, the network cannot lid huge areas [34].

IV. Basic classifications of the MAC protocols

In this part, we will briefly discuss the classifications of MAC for underwater networks and the developments that have occurred to improve and develop the ALOHA protocol. Fig.1 shows the upper classification of UWSNs MAC protocols. In this Figure, several important underwater MAC diagrams that were recently identified in the literature [34,35]. Moreover, this Figure showed that we can grade the MAC protocols to the three following sections.

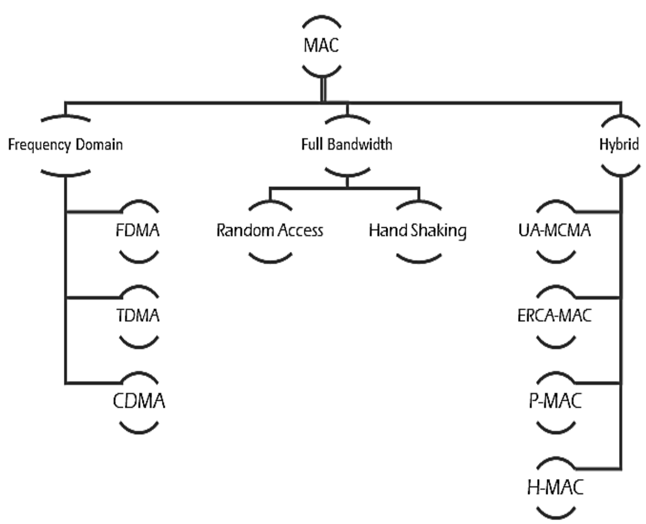

Fig. 1. The upper classification of UWSNs MAC protocols

A-Frequency Domain

Frequency domain MAC protocols for UWSNs were considered in previous research studies. Therefore, in this part, we review the frequency domain MAC protocols and their variations, which operate relied on the three main multiple-access technologies, Frequency Division Multiple-Access (FDMA), Time Division Multiple-Access (TDMA) and Code Division Multiple-Access (CDMA) as follows:

1) Frequency Division Multiple Access

FDMA is based on dividing the available frequency band to sub frequency bands and assigning every sub frequency band to only one user. As a result, to scheduling scheme, this user can only use the channel until it is released [36,37]. The total bandwidth of the FDMA channel is less than the original transmission channel bandwidth. Therefore, as a result to the finite bandwidth of the underwater acoustic channel and the shortcomings of the finite frequency band system to fading and multipath, the simple FDMA multiple-access technology is not fit for UWSN applications. Authors in [38] The MAC layer protocol based on FDMA.

2) Time Division Multiple Access

TDMA does not work like FDMA but divides time intervals (called frames) into multiple time slots to each node [37]. Every time slot is assigned to a single user. Intervals and upper bits are merged into frames. Increasing the guard time play an important role to prevent the collisions of data from adjacent time slots [38]. Therefore, due to its simplicity and flexibility, TDMA is a best multiple-access technology for UWSN. As a result, of the large propagation delay and delay variance through the acoustic channel, the accurate synchronization implementation between nodes is very difficult. Moreover, the protection periods need to be designed to disconnect various channels and reduce the possibility of occurrence collision the transmissions, data, which may lead to fewer channel uses [38]. The shortcomings of TDMA technology have been discussed in [39-47].

3) Code Division Multiple Access

CDMA has been introduced in [47], indicating that CDMA allows multiple users to work simultaneously on the whole frequency band, and noticed that signals from various users are distinguished using Pseudo Noise (PN) codes, which are used to propagate user messages [38]. This noise is filtered at the receiver by using so-called spreading codes to obtain the correct signal. CDMA technology is used to propagate transmitted data packets from one node to another node in the same level. In [48], the authors have been introduced a CDMA-based protocol MAC for underwater, which allows a periodic sleep mode to reduce energy consumption.

B-Full Bandwidth

Due to the spatial, temporal uncertainty issue, narrow bandwidth issue, near, far issue, synchronization issue, and weakness of the throughput performance, frequency domain MAC protocols are not suitable for UWSNs [49]. On the other hand, the full bandwidth MAC protocols have some features to avail the whole bandwidth of the connection channel and share network resources on-demand. So, most of the efforts on the design of the MAC protocols for UWSNs have concentrated on the design of the full bandwidth domain MAC protocols [50]. Table III shows the main differences between frequency domain and full bandwidth MAC protocols.

TABLE III
COMPARISON BETWEEN FREQUENCY DOMAIN AND FULL BANDWIDTH MAC PROTOCOLS

Factors	Frequency domain	Full bandwidth
scheduling	central	spread
Network resource sharing	Reserved for a certain user	On demand
Channel usage	Low	High
Appropriate network size	Small	big
Appropriate node density	Low	High
Appropriate network load	Low	High
Ratio of collision	Low	High
Energy consumption	Low	High
Throughput	Low	High
Propagation delay	High	Low
Used for	Small-scale network	Large-scale network

The full bandwidth MAC protocols can be divided to random-access and handshaking protocols as follows:

1) Random-Access

In this technique, the node starts transmitting at the moment it has packet ready to transmit [6,51]. If the receiver is not busy and there is no collision occurs, the data packet can be successfully received. In random access technologies, many nodes can randomly share the transmitting medium without control. We will talk in detail about this part in the next section, especially about the ALOHA protocol.

2) Handshaking

Handshake protocol is another important type of the full bandwidth MAC protocol, which is basically a set of reservation-based protocols [52]. The essential thought of handshake technique to avoid collisions is that the sender must check the status of channel by sending Request-To-Send (RTS) and Clear-To-Send (CTS) control packets in the control channel before sending any data. A handshake can be viewed as single and multiple channels, and in a single channel, MAC protocols can only take up one channel for data communication [53]. Channel handshake messages are exchanged before any payload is sent over only one channel [54,55]. One of the MAC protocols for handshake is a group of protocols aimed at achieving energy efficiency [56-58]. The multi-channel protocol is various from single channel MAC protocols; Multi channels, protocols use more than one channel for connection [59].

3) Hybrid Protocols

The hybrid protocols are the third part of MAC classification which benefit from the positive properties of both frequency domain and full bandwidth. Frequency domain protocols are more common for time-sensitive implementations because frequency domain protocols are more susceptible to multipath hidden terminal issues and have higher and long propagation delays. An Energy-efficient, Reliable, and Cluster-based Adaptive MAC (ERCA-MAC) protocol has been proposed in [60] to process the reliability of the network reliability and expand network life. This protocol splits the network into clusters and TDMA is utilized inside the cluster to avert collisions. Therefore, the suggested work can solve the issues of the hidden terminal inside one cluster. To increase network throughput and reduce the propagation delay compared to ERCA-MAC hybrid MAC protocols, authors in [61] suggested Underwater-Acoustic Multi-Channel MAC(UA-MCMA) that uses multi channels and lets simultaneous transmitting. This protocol combines both CDMA and a handshake mechanism that handles long propagation delay factor and low throughput ratio between neighbors from a single hop. Table IV shows the main variations between the ERCA-MAC and UA-MCMA protocols.

TABLE IV [20]
COMPARISON OF UA-MCMA AND ERCA-MAC HYBRID MAC PROTOCOLS

Factors	UA-MC MAC	ERCA-MAC
Network topology	Ad-hoc, stationary	Cluster, stationary
Collision rat	Medium	Low
simultaneous transmission	Yes, during one session	No
Throughput	High	Medium
Propagation delay	low	Medium
power consumption	Medium	Low
size of target packet	Small	Small
load of target network	High	Low
Channel usage	high	Low

In the following, we display some other exemplary hybrid MAC protocols for examples to exhibit their advantages and benefits.

Preamble-MAC (P-MAC) is considered a hybrid MAC protocol that was proposed in [62], which consists of a frequency domain protocol and a Slotted Multiple Access Collision Avoidance (Slotted MACA). P-MAC overcomes the low accuracy of time synchronization issues. P-MAC works dynamically and adaptively depending on the default distance level information, which is the file of evaluated and accumulated information of the channel state and change gained over periodic observation of the underwater environment.

Hybrid-MAC (H-MAC) protocol was introduced in [28]. To get the advantage of both frequency domain and random-access MAC protocols. The suggested MAC protocol splits the time frame into twain time slots, and each node uses one of the time slots to send data by a collision-free system. The second one is used for random access by the nodes to adjust to changing traffic terms. H-MAC protocol can achieve benefits from both frequency domain and random-access protocols with low power consuming ratio due to its capability to eliminate collisions and adapt to changing traffic Terms.

V. ALOHA PROTOCOL

As we mentioned earlier, we will talk about the random-access part in some detail. Random access can be split into two parts. The low data rate, scattered network, and tiny packet size are features wherever found in UWSNs makes the random-access technique is proper to them. In general, random-access techniques and other full bandwidth MAC protocols are used in large-scale.

In the random-access technique, the node simply starts sending when it has data ready to send [7]. If the receiver has no incoming data and there is no collision is occurring, in this case, the data packet can be successfully received. In random access technologies, a lot of nodes can randomly share the transmission medium without any control [7].

As shown in Fig. 2, random access protocols are divided into the Carrier Sense Multiple Access (CSMA) protocols and the ALOHA protocols [51].

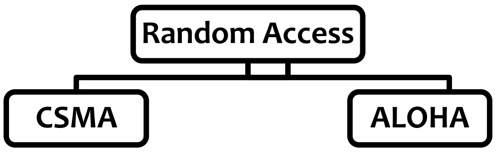

Fig.2. The classification of random-access pro tocols

The CSMA protocol is an analog class of random-access protocols. As all nodes must sense the needed channel for a certain interval of time before accessing the channel [63,64]. If the user listens to the channel before sending a packet, the unusual resources of the channel can be better used [65]. More details and changes to the CSMA scheme can be found in [65-68]. ALOHA protocol is the simplest MAC protocol for random access. This protocol can be carried out without any effort, and thus it cannot try to block packet collisions [52].

Although protocols based on RTS/CTS, such as CSMA have achieved better results than ALOHA protocols in terrestrial networks, their efficiency in UWSN may be very low due to the long propagation delay [69]. Fig.3 shows CSMA based on RTS/CTS.

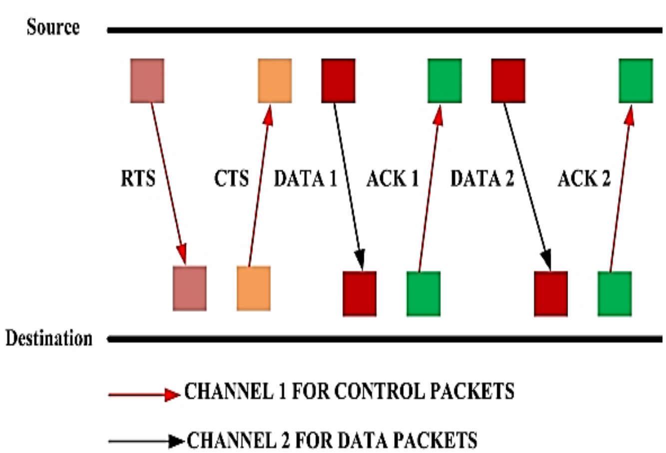

Fig.3. CSMA based on RTS/CTS

The ALOHA protocol has stable performance in terrestrial and underwater acoustic communication systems because its performance has nothing to do with propagation delay [70,71]. A stable performance makes the ALOHA protocols useful in networks that experience long relative propagation delays, such as underwater acoustics and satellite connection systems [16]. For this reason, ALOHA is considered the most important protocol for underwater acoustic networks with relatively large propagation delay [70,71].

TABLE V
THE MAIN DIFFERENCES BETWEEN CSMA AND ALOHA.

Factors	CSMA	ALOHA
Performance in WSNs	Stable	Stable
Performance in UWSNs	Not stable	Stable
Channel utilization	High	Low
optimization parameter	the carrier sense threshold that is adjusted	tune the mean back-off time
Energy consumption	Low	High
Collision rate	Low	High
Propagation delay	Very high in UW	High
Remining nodes in the network	Medium	Small

ALOHA is considered the simplest random-access MAC protocol. The protocol can be performed effortlessly, without any try to prohibit packet collision [52]. When there is no Acknowledgment (ACK) from the destination, it means that a collision occurs, or data distortion happens, and the node must send a packet again until having the ACK from destination. This scenario is shown in Fig. 4.

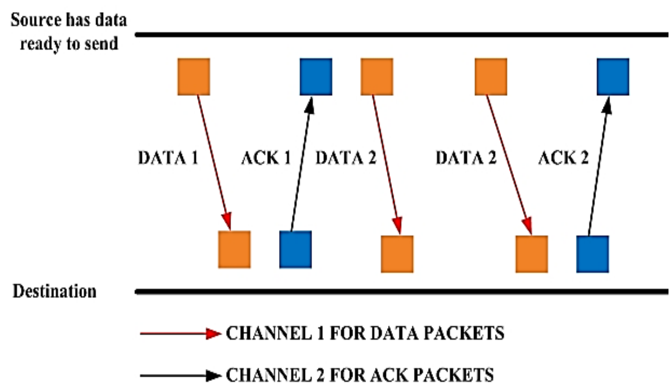

Fig.4. The process of sending and receiving packets in ALOHA protocol

In this part, we study the sequence of improving and developing the ALOHA protocol by studying some other protocols that were derived from it. Fig. 5 shows the derived protocols from the ALOHA protocol. Overviews of these protocols are as follows:

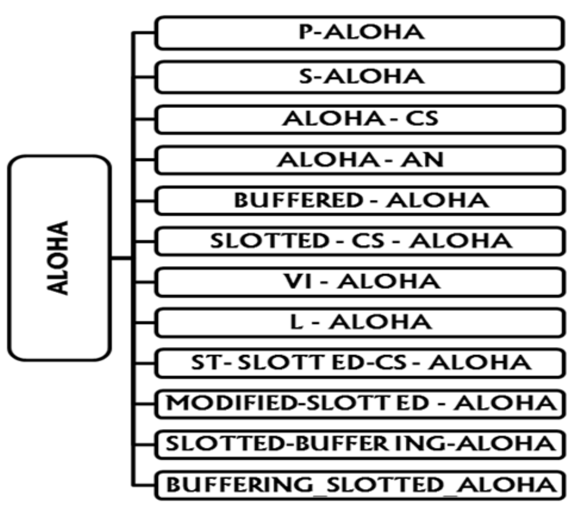

Fig. 5. ALOHA protocol and its derivations.

A. P-ALOHA

P-ALOHA refers to the Pure ALOHA protocol. In this protocol, data can be transmitted at any time when nodes have data ready to be sent. According to the ease of transmission in this protocol, when more than one node is sending data packets at the same time at this moment the collision occurs which affects the security of this data and causes a big problem as shown in Fig. 6 [72]. The node does not send another new packet until it receives an acknowledgment which refers to that the packet has reached its destination, so it waits for a while to receive an acknowledgment. On the other hand, if the time limit expires without receiving an acknowledgment, the node considers that the data packet or acknowledgment has been spoiled or lost. So, in this critical situation that the packet is destroyed due to a collision case, the node waits for a random period, after ending this random period the node can resend the packet again. The amount of delayed time should be randomly taken to avoid collision situations, otherwise, the same data packets will collide frequently [73]. Thus, pure ALOHA advises that at the timeout elapses, each node has to wait for a random amount of time before resending its data packet. This random period will support new collision avoidance and energy-saving, after this scenario, we can note that pure ALOHA protocol is like ALOHA protocol and no additives have been added and it also does not help reduce collision probability which leads to increased power consumption and does not try to improve throughput within the network.

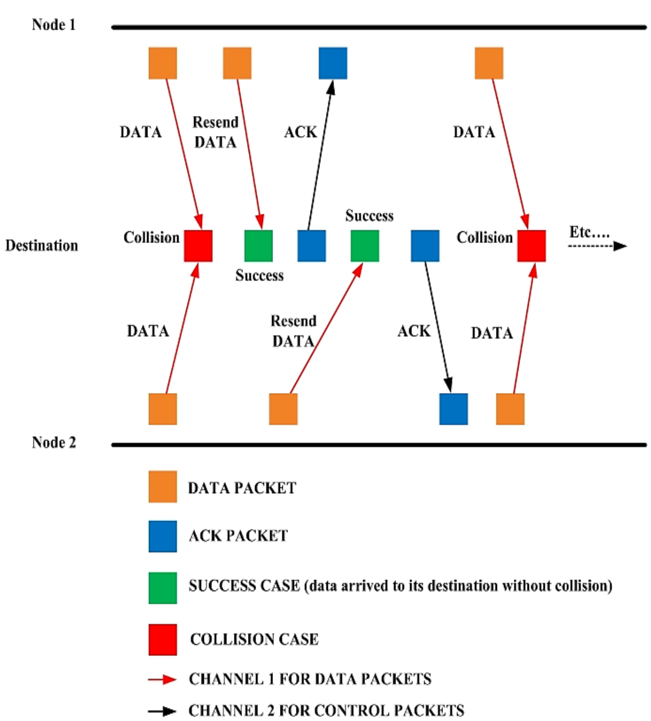

Fig. 6. All transmitting cases in P-ALOHA

B. S-ALOHA

S-ALOAHA refers to the Slotted ALOHA protocol. It was developed to enhance the performance of pure ALOHA in order to minimize the possibility of collision between packets while transporting these packets from nodes to their destination to reach these packets. So, the development process divided the time of the common channel into separate periods called time slots [63,74]. Therefore, at the beginning of each time slot, each node can only send one packet. Therefore, in the case where the node cannot lay the data packet on the channel at the beginning of the time slot, the time slot is missed that point, and the node must wait until the next time slot starts. If two or more nodes start to send data packets in the same time slot, as shown in Fig. 7, collisions may occur [75], and these data packets need to be retransmitted, and some energy will be wasted. Therefore, it can be seen from the previous discussion that the Slotted ALOHA protocol cannot achieve better performance than the ALOHA protocol [74,76]. The slotted ALOHA protocol can minimize the possibility of collusion, but neither minimize energy consumption nor maximize throughput.

C. *ALOHA-CS (ALOHA with Carrier Sense)*

This protocol can be considered as a final version of ALOHA with the advantage of the half-duplex technology (ALOHA-HD), whereby the sensor node will never send any new data packet if it is currently listening for a data packet within the network, in any case of whether it is the meant recipient of that data packet or not. Though the authors utilize the term “carrier sense” in this protocol to give the best advantage of knowing the channel status, ALOHA-CS does not use this advantage and does not attempt to spend extra time to see the status of the channel. Instead, it just simply checks if the half-duplex modem is currently receiving a data packet [62]. This protocol has taken the utility of a long propagation delay in the underwater acoustic environment. In addition, compared to pure ALOHA, this protocol provides a fundamental rise in network throughput ratio when the data packet size is large and there are a few nodes within the network. Otherwise, throughput decreases rapidly.

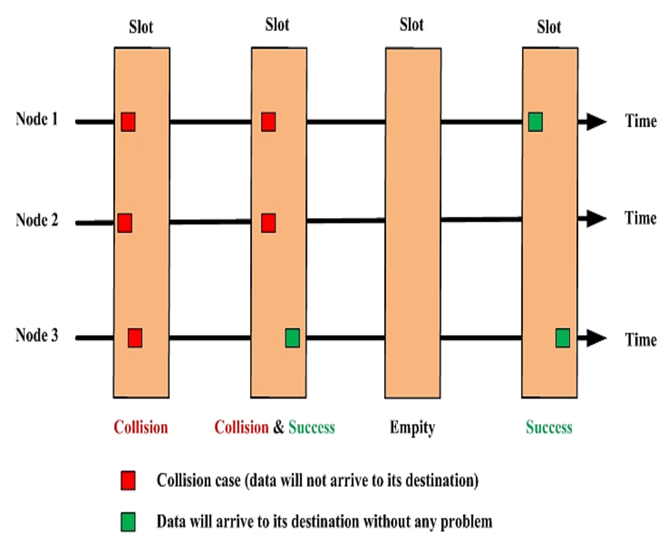

Fig. 7. The beginning of slot in the slotted ALOHA

D. *ALOHA-AN (ALOHA with Advance Notification)*

The design of ALOHA-AN is relying on a concept like ALOHA with Collision Avoidance (ALOHA-CA). The purpose of creating ALOHA-CA is to overcome the darkness of ALOHA-CS, although it is agreed that the advantage of ALOHA-CS is that it at times helps abstain from sending a data packet when listening to another sensor node within the respective network [65]. In addition, the listening process performed by a sensor node serves to sometimes help to minimize the possibility of collisions [65]. Collecting and storing more information is necessary to ALOHA-AN, so it requires additional resources other than ALOHA-CA [65]. Nevertheless, ALOHA-AN can realize a better throughput ratio and collision avoidance through only higher costs [52]. This protocol also provides a high rise in network throughput ratio compared to pure ALOHA when the packet size is large and with few nodes within the network. The performance of this protocol is high when the packet size is large, and the numbers of the nodes are few. But the throughput decreases rapidly with the small size packets and a high-density network.

E. Buffered ALOHA Protocol

Several studies have utilized the buffer to enhance the performance of the ALOHA protocol, such as [77,78]. In [79] authors proposed an approximate method to analyze the S-ALOHA system by using a limited user group with a limited or unlimited storage capacity. Their method depended on the assumption of channel asymmetry. The analysis of the system performance is determined by the performance of arbitrarily selected users, which they call tagged users. Whereas the authors in [80] analyzed the implementation of slotted ALOHA based on a limited set and more packet buffers. While the behavior of the hybrid ALOHA/TDMA protocol using buffers on each client-side has been studied in [81]. Finally, the authors in [71] proposed the Buffered ALOHA protocol and studied the impact of buffering on the throughput of ALOHA. In this study, the authors presented a derivation for measuring ALOHA throughput under a given number of active nodes. They separate the causes for the failure to send in three reasons: the presence of dropped data packets and twain types of collisions on the common distribution channel. At the end of the article, we note that this protocol focused on the element of productivity only and did not care about any other elements such as the effect of delay and energy consumption because the buffer increases the delay process.

F. Slotted_CS_ALOHA

The authors in [82] outlined a major problem found in Underwater (UW) and proposed a Slotted Carrier Sense ALOHA protocol (Slotted_CS_ALOHA). This protocol attempted to solve an energy consumption issue since the sensor node is powered by batteries, which are not easily recharged. Moreover, when a collision occurs while sending a packet from the source to its destination, we need to send this packet again, this action wastes energy. Therefore, after a short period of time, the sensor node will transfer to a useless state and stop serving, and the data in this field will be wasted and not covered. So, the authors in [82] tried to solve this issue by putting the sensor node in sleep mode to reduce power consumption before this shift the node is allowed to generate more than one packet and go to sleep, this packet will go to the buffer and use the two conditions slot time and CS to reduce the possibility of collusion. In addition, there is a second buffer that will be responsible for handling the ALOHA cycle and passing only one packet to it and when the packet reaches its destination successfully, it will send another packet, etc. We observed that this protocol did indeed save process power consumption and improved the throughput rate but failed to improve the average delay.

G. *VI-ALOHA*

We are discussing this protocol and found that this protocol is specifically designed to avoid the probability of collision. This protocol splits the broadcast channel into a long time slot. But the authors in [83] proposed a Variable Interval ALOHA (VI-ALOHA) protocol with randomly change of interval time slot make a comparison between VI-ALOHA and Equal Interval ALOHA (EI-ALOHA) to illustrate the effect of the two protocols and how can they minimize collision by increasing randomness in space and especially in the VI-ALOHA. The VI-ALOHA protocol is relying on at most twain factors. First, the variable interval to reduce the beacon coverage intersection. Second, it utilizes the Poisson random distribution method to generate a random beacon interval, which increases the randomness of every beacon broadcast and reduces collisions caused by equal intervals as shown in Fig.8. On the other hand, the EI-ALOHA is similar to the S-ALOHA so when the authors made a comparison of the VI-ALOHA and the EI-ALOHA, the VI-ALOHA gave better results than the EI-ALOHA.

H. *L-ALOHA protocol*

The Learning-ALOHA (L-ALOHA) protocol deals with two parts in its implementation as the authors said in [84]. The first section relies on the learning algorithm, that is, the node sends the packet at a random interval to find a good interval that the collision does not occur when a packet is sent through it to avoid data retransmission once again. While the second part is the stable part when the learning process of the entire network is stable. When each node has data ready to be exchanged through the network, it only needs to be capable of sending packets according to a fixed time. We noted that the authors of this work perform a comparison between its protocol and S-ALOHA and P-ALOHA only and they made a comparison of two factors only (throughput and average delay) to show the extent of the superiority of their protocol that has better results than other comparison protocols, and forget the strongest factor in the underwater network, which is the consumption of energy since if they take this factor into this comparison their protocol will not get better results as the process of learning is consuming higher energy until reaching the stage of stability. Moreover, P-ALOHA is ALOHA itself and s-ALOHA are the first protocol generated to improve the ALOHA protocol, so these protocols are old to use to demonstrate the extent of the superiority of the proposed protocol.

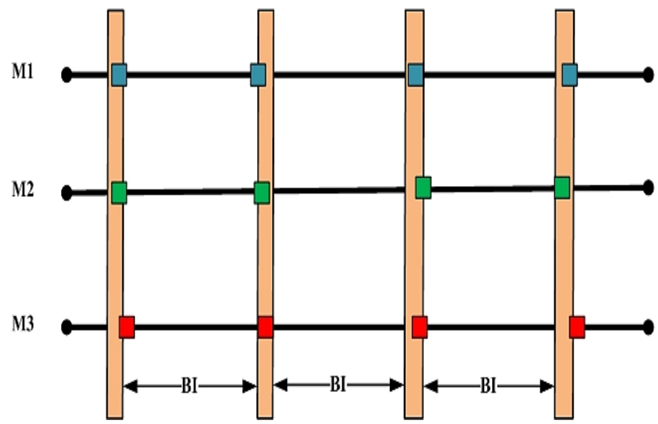

Fig.8 Variable Interval ALOHA

I. ST-Slotted–CS ALOHA

Saving Time Slotted Carrier Sense ALOHA protocol is considered as the updating of Slotted_CS_ALOHA protocol that authors in [85] are proposed to update the performance of Slotted_CS_ALOHA protocol. This protocol uses to avoid the long propagation delay and save time by using only one buffer to let the node generate and send more than one packet and modified the position of the other buffer that allows data to be sent back to the intended destination again, especially in the event of the collision case. The results showed that the ST-slotted–CS ALOHA gives better results than Slotted_CS_ALOHA especially in reducing energy consumption, increasing the throughput ratio, and reducing the average delay factor, but it gives poor results in the number of dropped nodes compared to the Slotted_CS_ALOHA protocol.

J. Modified-Slotted-ALOHA

The Modified-Slotted-ALOHA protocol is a suggested protocol designed to resolve problems related to other ALOHA protocols [86]. This protocol uses a modulated buffer to help in creating more than one packet and resend them instead of a node when an ACK is not received. This modulated role will economize energy that the sensor nodes would otherwise waste. The protocol resolves the issues of low throughput ratio, high energy consumption ratio, and the high average delay factor by utilizing a buffer, which is utilized to save data packet before sending it so that it can resend when a collision occurs or an ACK is not received. This will raise the data transfer average and overcome the power consumption problem. The suggested protocol relies on the use of back-off technology, which utilizes random time to select the proper time to resend the data again to avert the collision. This protocol could reduce the power consumption ratio, and average delay factor more than the other protocols. In addition, it results in a higher throughput rate.

K. Slotted-Buffering-ALOHA

The Slotted-Buffering-ALOHA protocol has been widely utilized for saving energy leading to extended network lifetime [87]. The efficiency of energy has an attendant trading-off with delay. This protocol is intended to resolve problems that were specified by the previously explained ALOHA protocols. In this protocol, more conditions are used to assure that a collision does not occur. The first condition cannot send any data packets by the node prior to the start of the time slot. The posterior condition is to use carrier sensing (CS) to send shortened messages over the control channel to characterize the state of the connection channel, to ensure that there are no data in the communication channel, and therefore no collision occurs, and no data packet is lost. Another substantial element of this protocol is the use of buffers to help create multiple packets, and if no ACK is received, they are retransmitted according to the behavior of the node. These modulated roles will economize energy that the sensor nodes would otherwise waste. Furthermore, this protocol resolves the problems of low throughput ratio, and rise average delay factor. This protocol can also extend the network lifetime by using a buffer used to store data prior to it being sent to resend it again in the event of a collision or no ACK is obtained. This buffer is used, additional conditions to resend the packet again, which are represented in the communication channel is free of any transmitted data and the slot time has not still started. These additional conditions will increase the data transfer rate and overcome the power consumption problem.

L. *Buffering_Slotted_ALOHA*

The Buffering_Slotted_ALOHA [7] is a new protocol to deal with the common problems there are in UW [30-31]. This protocol divides the available network for small segments called closed groups to decrease the movement of the nodes from one group to another. Every closed group within the available network has some small pool with a specified number of nodes for reducing the traffic within the group which lead to avoiding the collision and thus reducing the time of sending to a minimum. An Under Water Sink (UW-Sink) node is another essential element there is in the closed group which considers as a leader reacts with a small number of nodes within this closed group. The ease of this interaction is due to the benefit of using small groups and placing the nodes in them. The Under Water Main Sink (UW-Main Sink) is the main sink node there is outside the closed groups that interact with data coming from UW-Sink or normal nodes that there are within the closed groups. The status of a time slot lets each node in the closed group deal with the UW-Sink as a default choice if it's available or deals with the UW-Main Sink as another choice if the default choice is not available as shown in Fig. 9. Furthermore, the sending data packet is stored in a buffer there is in each node till it is confirmed. A large storage capacity is an attribute that distinguishes this buffer and lets it for storing many data packets. Before sending, checking the slot case is an important goal to speed up the sending operation. Fig. 9 also shows the topology of this network. We noted that this protocol can increase the network throughput ratio and decrease the average delay factor and the energy consumption ratio. In Table VI, a comparison of ALOHA protocols is given according to energy consumption, average propagation delay, throughput, and dropped nodes.

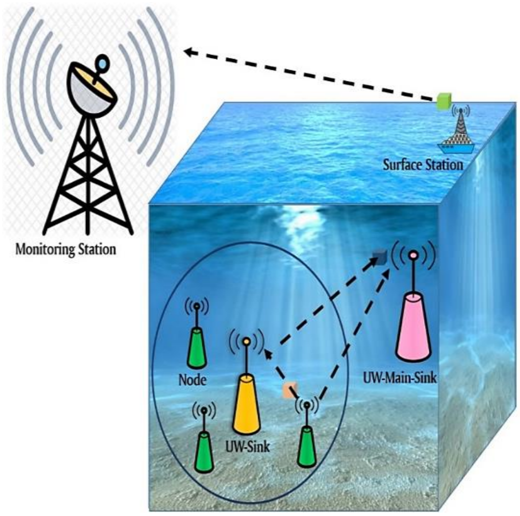

Fig. 9. Topology of Buffring_Slotted_ALOHA protocol

We can note that the P-ALOHA protocol is like the ALOHA protocol. It does not reduce the collision probability which leads to an increase in the power consumption, and it does not improve the network throughput. The S-ALOHA protocol can minimize the possibility of collusion, but neither minimize energy consumption nor maximize throughput. While the ALOHA-CS protocol supplies a fundamental increase in the throughput of the network compared to the P-ALOHA when packet size is large and there are a low number of nodes within the network. Also, the efficiency of the ALOHA-AN protocol is high when the packet size is large, and the numbers of the nodes existing are low. The throughput value is reduced rapidly with the packets of small sizes and a high-density network, as illustrated in Fig. 10, 11, 12, and 13.

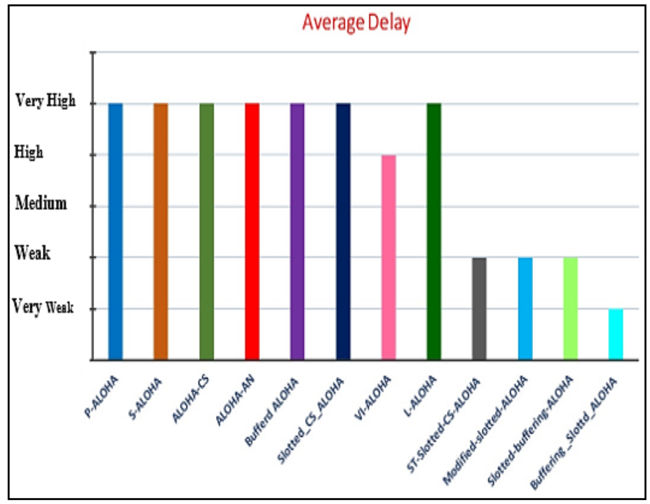

Fig. 10. Average delay comparison between different ALOHA protocols

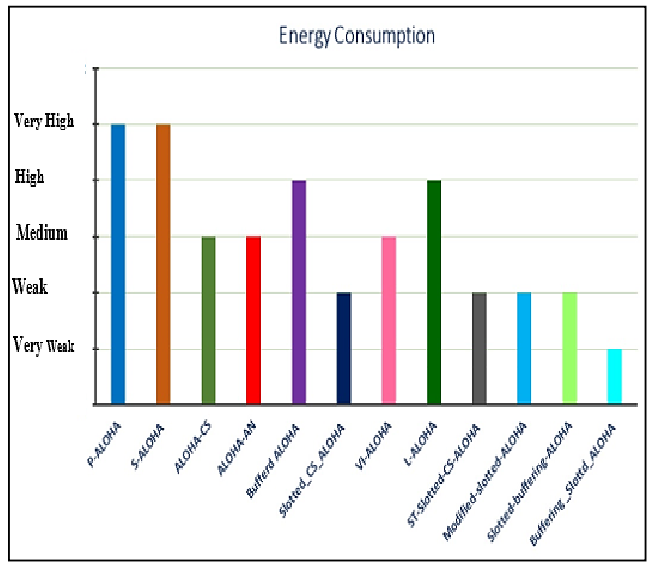

Fig. 11. Energy consumption comparison between different ALOHA protocols

TABLE VI.
THE PRIME DIFFERENCES BETWEEN THE ALOHA PROTOCOLS.

Comparison Protocols	Average Delay Factor	Energy Consumption Factor	Dropped Nodes Factor	Throughput Factor
P-ALOHA	Very High	Very High	Very High	Very Weak
S-ALOHA	Very High	Very High	Very High	Very Weak
ALOHA-CS	Very High	Medium	Medium	H(LPS-SNN) L(SPS-LNN)
ALOHA-AN	Very High	Medium	Medium	H(LPS-SNN) L(SPS-LNN)
Buffered-ALOHA	Very High	High	High	Medium
Slotted_CS_ ALOHA	Very High	Weak	Weak	High
VI-ALOHA	High	Medium	Medium	Medium
L-ALOHA	Very High	High	Very High	Medium
ST-Slotted-CS-ALOHA	Weak	Weak	High	High
Modified-Slotted-ALOHA	Weak	Weak	Weak	High
Slotted-buffering-ALOHA	Weak	Weak	Weak	High
Buffering _Slottd_ALOHA	Very Weak	Very Weak	Very Weak	Very High

H(LPS-SNN) refers to High (Large Packet size- Small Numbers of nodes)
L(SPS-LNN) refers to Low (Small packet size-Large Numbers of nodes)

The Buffered ALOHA Protocol focused on productivity only and did not care about other elements such as the delay and the energy consumption. In this protocol, the existence of a buffer increases the delay in the network. The Slotted_CS_ALOHA protocol saves the processing power consumption and improves the throughput rate, but it fails to improve the average delay. On the other hand, the EI-ALOHA protocol is like S-ALOHA, so when the authors make a comparison of both VI-ALOHA and EI-ALOHA, VI-ALOHA gives better results than EI-ALOHA. While, in the L-ALOHA protocol, we noted that authors perform a comparison between this protocol and the S-ALOHA and the P-ALOHA only and they made a comparison of two factors only (throughput and average delay) to prove the extent of the superiority of their protocol that has the best results of the other comparison protocols forgetting the strongest factor in the UNW, which is the energy consumption. If they take this factor into account, their protocol will not get the best results. Moreover, P-ALOHA and S-ALOHA are the first protocols generated to improve the ALOHA protocol. These protocols are something old to use to demonstrate the extent of the superiority of the new protocols.

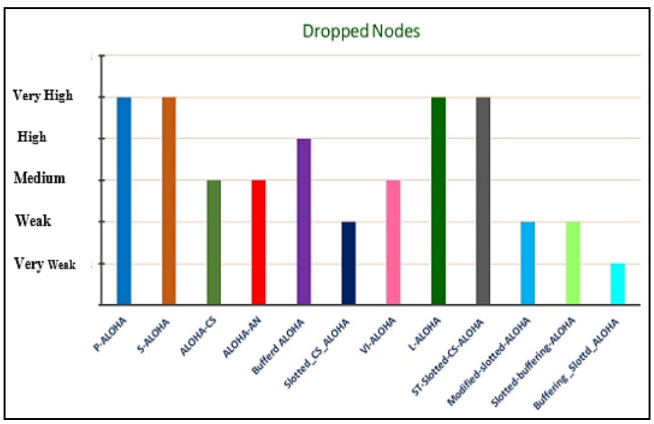

Fig. 12. Dropped node comparison between different ALOHA protocols

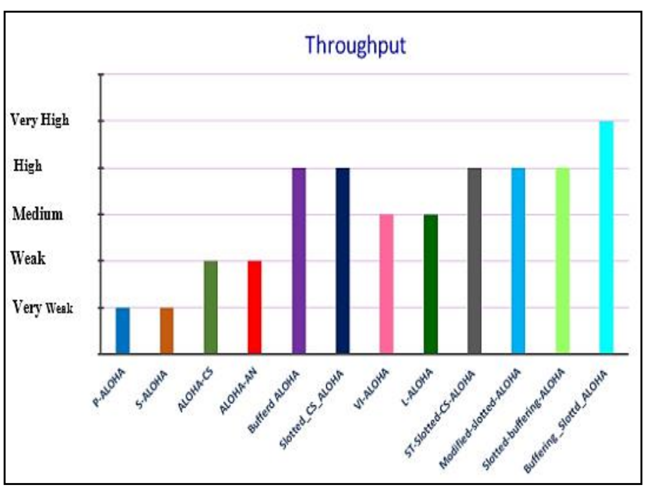

Fig. 13. Throughput comparison between different ALOHA protocols

The S-slotted–CS ALOHA gives better results than the Slotted_CS_ALOHA especially in reducing the energy consumption, increasing the throughput ratio, and reducing the average delay factor, but it gives lower results in the number of dropped nodes than the Slotted_CS_ALOHA protocol. Modified-Slotted-ALOHA protocol has less power consumption ratio and average delay factor than the other protocols. The Slotted-Buffering-ALOHA protocol, which uses a buffer and additional conditions to resend the packet again has a high throughput rate. Finally, we noted that the Buffering_Slotted_ALOHA protocol can decrease the average delay factor and the energy consumption ratio and increase the network throughput ratio.

VI. Conclusion

Our literature introduces the fundamentals of UWSN and underwater MAC protocols. It supplies a comprehensive survey of the recent UWSNs MAC protocols. Some of the proposed works use different techniques to solve the network performance problems. Protocol design is an important factor in our research to compare MAC proposed protocols in the literature. In this paper, we also presented in detail the great role of ALOHA protocol and the sequence that happened to improve and develop the ALOHA protocol by discussing some other protocols that were derived from it such as P-ALOHA, S-ALOHA, ALOHA-CS, ALOHA-AN, Buffered ALOHA, Slotted_CS_ALOHA, VI-ALOHA, ST-Slotted–CS ALOHA, Modified-Slotted-ALOHA, Slotted-Buffering-ALOHA, and Buffering_Slotted_ALOHA protocols. Finally, we illustrated a comparison of the ALOHA protocols. The comparison proved that the Buffering_Slotted_ALOHA protocol can give the best results because it can decrease the average delay and the energy consumption ratio and can increase the network throughput ratio, unlike the others.

VII. List of Abbreviations

The abbreviations used in this survey are listed in Table VII.

TABLE VII.
LIST OF ABBREVIATIONS

ACK	Acknowledgment
ALOHA-AN	ALOHA with Advance Notification
ALOHA-CA	ALOHA with Carrier Sense
ALOHA-CS	ALOHA with Collision Avoidance
CDMA	Code Division Multiple Access
CS	Carrier Sense
CSMA.	Carrier Sense Multiple Access
CTS	Clear-To-Send
EI-ALOHA	Equal Interval ALOHA
ERCA-MAC	Energy-efficient, Reliable, and Cluster-based Adaptive MAC
FDMA	Frequency Division Multiple Access
H(LPS-SNN)	High (Large Packet Size- Small Numbers of Nodes)
H-MAC	Hybrid-MAC
KHz	kilo Hertz
L(SPS-LNN)	Low (Small Packet Size-Large Numbers of Nodes)
L-ALOHA	Learning ALOHA

continued on the next page

TABLE VII.: CONTINUED

MAC	Media Access Control
MACA	Multiple Access Collision Avoidance
P-ALOHA	Pure ALOHA
PN	Pseudo Noise
P-MAC	Preamble-MAC
RF	Radio Frequency
RTS	Request-To-Send
S-ALOAHA	Slotted ALOHA
Slotted_CS_ALOHA	Slotted Carrier Sense ALOHA
ST-Slotted–CS ALOHA	Saving Time Slotted Carrier Sense ALOHA
TDMA	Time Division Multiple Access
TWSNs	Terrestrial Wireless Sensor Networks
UA-MC MAC	Underwater-Acoustic Multi-Channel MAC
UW	Under Water
UW-ASNs	Underwater Wireless Acoustic Sensor Networks
UW-Main Sink	UnderWater Main Sink
UW-Sink	UnderWater Sink
UWSNs	underwater wireless sensor networks
VI-ALOHA	Variable Interval ALOHA
WSNs	Wireless Sensor Networks

AUTHORS CONTRIBUTION

Ehab Khater, Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Software; Roles/Writing – original draft.

Nawal El-Fishawy, Conceptualization; Resources; Supervision; Writing – review & editing

Maha Tolba, Resources; Roles/Writing – original draft

Dina Ibrahim, Project administration; Resources; Software; Validation

Mohammed Badawy Conceptualization; methodology, Resources; Supervision; Writing – review & editing

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TITLE ARABIC:

مراجعة بروتوكولات MAC المستندة إلى ALOHA لشبكات الاستشعار اللاسلكية تحت الماء

ARABIC ABSTRACT:

أصبحت البيئة المائية أكثر وضوحًا وقابلية للتحكم منذ أن تدخلت شبكات الاستشعار اللاسلكية تحت الماء (UWSNs) لاكتشافها، لأن شبكات الاستشعار اللاسلكية تحت الماء توفر وتدعم العديد من التطبيقات المدنية والعسكرية بكفاءة، وقد تم تحلل العديد منها واستخراجها للمساعدة في تجنب السقوط. في العديد من المشاكل، مما تسبب في العديد من الخسائر المادية والاقتصادية. يلعب بروتوكول التحكم في الوصول إلى الوسائط (MAC) دورًا مناسبًا لتحسين أداء الشبكة مما يساعد على إنجاز المهام المطلوبة من الشبكة بسرعة وبدون تكلفة إضافية. يعد النطاق الترددي المنخفض والمحدود والطاقة والذاكرة المحدودة وتأخير الانتشار الطويل والمتغير ومعدل الخطأ المرتفع في البتات بعض التحديات التي تواجه تصميم بروتوكول MAC لشبكاتUWSN. بروتوكول ALOHA هو أحد أكثر بروتوكولات MAC شيوعًا. في هذه المقالة ، نركز على تقديم مراجعة لأحدث تطورات بروتوكولات ALOHA الخاصة بـ UWSN. هذه البروتوكولات هي P-ALOHA و S-ALOHAو ALOHA-CS و ALOHA-AN و BUFFERED-ALOHA و SLOTTED-CS-ALOHA و VI-ALOHA و L-ALOHA وST- SLOTTED-CS-ALOHA MODIFIED-SLOTTED-ALOHA و SLOTTED- BUFFERING-ALOHA و BUFFERING_SLOTTED_ALOHAمتبوعًا بمناقشات حول خصائص وقيود كل بروتوكول ALOHA بالإضافة إلى شرح المقارنات بين جميع هذه البروتوكولات وفقًا لمقاييس الأداء المختلفة وهي متوسط عامل التأخير ونسبة استهلاك الطاقة وعامل العقد الساقطة و نسبة الخرج.