Surveys of Design Considerations for Underwater Networks

Nejah Nasri, Abdennaceur Kachouri, Laurent Andrieux, and Mounir Samet

***Abstract*—The underwater ocean environment is widely regarded as one of the most difficult communications channels. The ocean is a temporally and spatially varying propagation environment. So Low communication bandwidth, large propagation delay, floating node mobility, and high error probability are the challenges of building mobile underwater wireless sensor networks (UWSN) for aquatic applications. These challenges are area of research in order to develop a networking system that can cope with the adverse underwater communications environment. This paper discusses several issues regarding underwater networks. These include topology considerations, multiple access methods, and MAC [1]protocols.**

***Index Terms*—Underwater communication, wireless sensor networks, acoustic signal, networking protocols.**

I. Introduction

Underwater sensor network (UWSN) is a novel technique that provides a promising solution for efficiently exploring and observing the aqueous environments. UWSN consists of variable number of sensors that are deployed to perform collaborative monitoring tasks over a given area. Indeed several acoustic applications under marine require a permanent use of this network, therefore an important consumption of energy; that limits the life of battery and therefore the robustness of the network. The provisioning of energy is a major constraint in underwater wireless systems [1].

This constraint is due to the difficulties encountered to change the batteries of underwater stations. The change of the underwater stations batteries requires the recovery of equipment; this operation takes a significant time, stalls the system, and is expensive. For thus the focus of network, design is on scalable multiple access methods, and Mac (Medium Access Control) protocols, which are applicable to varying coverage area, long propagation delay and strict power requirements encountered in the underwater environment [2].

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[1] Media Access Control

The remainder of the paper is organized as follows: In Section (1), we discuss the associated MAC protocol and access techniques stack for underwater communications and we draw the main conclusions. In section (2) we provide a classification schemes for underwater networks, which represents several keys in determining the type of network deployed.

II. Topologies Consideration for Underwater Sensor Networks

Depending on the application, future underwater networks are likely to evolve in two directions: centralized (single hop) and decentralized (multi hops) networks [3]:

- Centralized network: nodes are placed around of a central station that covers one cell. Larger area is covered by more cells whose base stations are connected over a separate communications infrastructure. The base stations can be on the surface and communicate using cable or acoustic links.

This topology presents several inconveniences:

- When the central node is in breakdown all the nodes is out network.

- This topology does not permit to cover big surfaces because of the limit of the range of the modem of the central station.

- Decentralized network: nodes communicate via peer-to-peer, multi-hop transmission of data packets. The signal passes from the nearest nodes of the emitter to the distant nodes in the direction of the receptor. Intelligent algorithms adapted to the different conditions manipulate the routing of information. This topology is able to cover height distances, on other hand the delay of propagation increases with the number of hops.

III. Choice of Access Technique Schemes for Underwater Communication

Underwater wireless sensor networks (UWSN) prosecute a large mutation resulting of limited bandwidth, especially when multiple users split a common channel. The major objectives underwater communication system is to maximize the channel capacity and to minimize latency time between a station deciding to transmit and able to transmit.

In this subsection, we present comparative study between typical multiple access schemes in order to adapt the best technical access for underwater channel communication. The most important access techniques are [4]:

- Frequency Multiplexing (FDMA[2])
- Temporal Multiplexing (TDMA[3])
- Code Multiplexing (CDMA[4])

A. FDMA /TDMA Multiplexing

Both frequency divisions multiple access (FDMA) and time division multiple access (TDMA) are the most signifying access schema, usually used in radio communication. With FDMA, the entire available frequency band is divided into sub band. With TDMA, the time axis is divided into time slots, every node is allowed to transmit without restraint during the slot assigned to it. The slot assignments follow a predetermined pattern that repeats it self periodically.

The main advantages of both FDMA and TDMA for under water communication are: FDMA and TDMA insure that each transmission is successful and no control messages are required. FDMA does not require synchronization between the nodes.

In other side, FDMA and TDMA are inefficient, when the load is uneven. In addition, these two techniques are not flexible; adding a new node to the network requires equipment or software modification in every other node. In fact, FDMA finds his limits in aquatic environment, because of limited spectrum resources, and fading problem .TDMA in aquatic channel require complex synchronization techniques to avoid collisions due to large propagation delay, and floating node mobility. For thus TDMA schema is not scalable, as it rapidly losses efficiency on an underwater channel because of energy consumption.

Since the important performance measures of multiple access schemes are interested their throughput and delay. The throughput equals the fraction of time in which the channel is engaged in the successful transmission of node data. The delay is the time from the moment a message is generated until it makes it successfully across the shared channel.

The characterization of TDMA delay overlooks the impact of access delay each node may experience while waiting for its allocated slot. This oversight results in a biased comparison of FDMA and TDMA. Actually contrarily to RF channel in underwater channel Propagation delays are only media and distance dependent.

Due to the limitations to the acoustic propagation speed and the limited bandwidth, protocols based on time or frequency scheduling alone are severely restricted in terms of coverage. For thus we must combine FDMA/TDMA techniques as showing in figure (1):

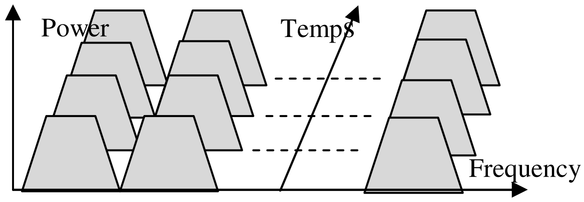

Fig.1. TDMA/FDMA access schema

B. Code Division Multiple Access

In this type of multiplexing all users or messages have a simultaneously access to the totality of bandwidth; every user is differentiated by a code that has been allocated in the beginning of the communication. There are several mode of CDMA, notably the direct sequence CDMA, noted DS-CDMA, and hopping frequency CDMA, noted FH-CDMA.

Code division multiple access (CDMA) implemented with direct sequence spread spectrum (DSSS) signaling is among the most promising multiplexing technologies for underwater sensor networks (UWSNs).

Compared to TDMA and FDMA the advantages of CDMA for underwater channel include:

- Superior operation in multipath environments by exploiting Rake filters at the receivers.
- Flexibility in the allocation of channels; increasing channel reuse by decreasing packet retransmissions.
- The ability to operate asynchronously.
- Enhanced privacy.
- Increased capacity in bursty or fading channels (robust for frequency selective fading).
- Less sensitivity to noises (Minimizing the mutual interferences).
- Better diversity on frequency.
- Permit receivers to distinguish among signals simultaneously transmitted by multiple s devices.
- Decrease energy consumption and increase networks throughput.

Interestingly, for underwater channel FH-CDMA leads to a higher bit error rate than DS-CDMA. In other hand the transmission rate must be reduced to allow for the coding or frequency hopping implementation.

The table below shows a comparative study between access schemes needed for underwater communication:

TABLE I
FDMA-TDMA-CDMA PERFORMANCE IN UNDERWATER CHANNEL

	FDMA	TDMA	CDMA
Scalability			×
Complexity		×	
Security			×
synchronization		×	
Throughput	×		×

FDMA and TDMA schemes do not utilize the shared channel very efficiency, they are nor flexible for the changing numbers of underwater nodes. For thus theses two techniques are not suitable for the underwater environment. CDMA is a conflict-free multiple access

[2] Frequency Division Multiple Access
[3] Time Division Multiple Access
[4] Code Division Multiple Access

method which is promising for future underwater networks.

IV. MEDIA ACCESS CONTROL PROTOCOLS FOR UNDERWATER COMMUNICATIONS

Selection of suitable MAC protocol has a great impact on the system efficiency and is especially important for channels with low quality and high latency, such as underwater channel. Many protocols have been developed in order to provide an equitable sharing of underwater channel. In this subsection, a family of medium access control protocols for underwater communication is specified and analyzed to ensure best underwater communication.

A. ALOHA Protocol

The idea of the protocol is: free access to the channel when user has data to transmit. In these conditions, it is clear that collisions occur. While «listening to» the channel during the transmission, the user can know if a collision took place and broadcast data. The inconvenient of this protocol is: the probability of collisions increase when the system is too charged.

B. CSMA protocol

The CSMA (Carrier Sense Multiple Access) consists on the listening the transmission channel, if the channel is free, the station transmits her message. Several protocols belonging to this family of which the difference residing in their reaction facing a busy channels [4]:

- Persistent CSMA: the station listens to the channel and transmits his message when the channel becomes free.
- Non persistent CSMA: the station stops listening to the channel during uncertain time before testing if the channel is free.
- P-Persistent CSMA: the station transmits its message when the channel is free only with a P probability. If the channel is occupied, the station proceeds as in the non persistent case. In order to decrease the probability of collision the amelioration consists in stopping immediately the emission when a station detects a collision, in order to free the channel as soon as possible and to win of the time. Besides, it permits to reemission the lost message. This algorithm is known as CSMA/CD (Carrier Sense Multiple Access with Collision Detection) used by Ethernet 802.3. Different problems make impossible the setting up of the CSMA/CD.

Indeed in underwater wireless sensors networks, the limitation of acoustic links due to the transmission ranges, and the adverse underwater communications environment can entail the problem of hidden terminal and the problem of station exposed.

Here we deduct that this protocol can limit the throughput channel. Because carrier sense does not provide the relevant collision avoidance information, we chose to seek another approach based on MACA5, which we describe below.

C. MACA protocol

In MACA protocol the emitter before transmitting his message it sends a Request-to-Send (RTS) packet to the receptor; this RTS packet contains the length of the proposed data transmission [5].If the receptor hears the RTS, and it is not currently transmitting (which we explain below), it immediately replies with a Clear-to-Send (CTS) packet; this CTS also contains the length of the proposed data transmission. As showing in figure 2 upon receiving the CTS, station A immediately sends its data.

MACA protocol can eliminate problem of hidden and exposed terminal, in fact in the hidden problem station C would not hear the RTS from station A, but would hear the CTS from station B and therefore would defer from transmitting during A's data transmission. In the exposed problem, station C would hear the RTS from station B, but not the CTS from station A, and thus would be free to transmit during B's data transmission.

D. MACAW Protocol

MACAW [6] is a modified version of MACA, which includes a MAC level acknowledgment (ACK). IEEE 802.11 standard uses a variant of MACAW along with CSMA. The advantages of MACAW a protocol is that avoid collision between RTS /CTS.

As showing in figure (2) in MACAW protocol when a node A wants to send a packet to node B, it initially sends a small packet called Request-to-Send (RTS). Upon correctly receiving the RTS, node B responds with another small packet called Clear to-Send (CTS). After receiving the CTS, node A sends the DATA packet to node B. If node B receives the DATA packet correctly, it sends an Acknowledgment (ACK) back to node A.

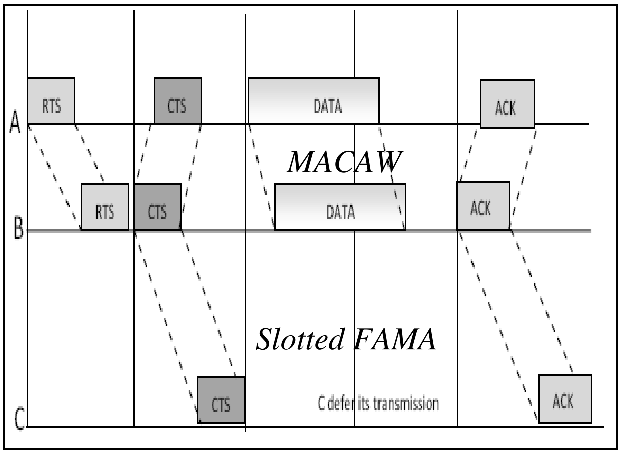

Fig. 2. The use of virtual channel sensing (MACAW and Slotted FAMA protocols)

After presenting the most important MAC protocols used in underwater systems we present in the remainder of the paper a comparative study between all these access techniques.

[5] Multiple Access with Collision Avoidance

[6] Multiple Access with Collision Avoidance for Wireless

V. Explanations and Conclusions of Underwater Networks System

The balance between media access control and throughput/delay continues to be of high interest to the research and operational communities. Occasional surveys of the current state of the art are useful to researchers to help keep them abreast of emerging capabilities. In the following, section we discus the underwater MAC protocols, we adds new significant information, however, and provides a comparison basis for the current techniques.

A. Taxonomy of underwater operating networks

In this party a range of MAC protocols have been studied in order to dress underwater network taxonomy. Figure (3) show a distribution of the different Mac protocols according to the traffic of channel, coverage zone and according to the distribution of nudes.

In fact for a network with small coverage zone, we use single-hop network, FDMA or TDMA, as methods of access and aloha as a protocol of communication. If we aim to increase the coverage zone with stationary traffic we use a centralized topology (dense topology) and CSMA, MACA, or FAMA Protocols. If the coverage zone and the throughput are scalable we used a decentralized topology (communications will require multiple hops to reach destinations) and CSMA with RTS/CTS/DATA/ARQ handshakes.

For increasing traffic we use a FAMA[7] protocols to prevent collision between RTS/CTS/ACK and data packet. Multi hop underwater networks are used to cover long communication distance. As assumed previously that multi-hop topology suffer from hidden problem for thus MACA and MACAW protocols are used with CDMA access technique to insure best scalability in underwater networks.

B. Analysis of underwater MAC protocols

Mac protocols issues in underwater systems and network systems are extremely important. In This subsection we present analysis studies in a range of topologies including peer-to-peer networks, and a range of MAC protocols.

Several MAC protocols have been proposed recently that attempt to provide sufficient operation .Most proposals have focused on random access techniques, but some have used a fully synchronized approach. So the Seaweb [6] project (real application of the aquatic networks), use FDMA as an access technique which is not efficient because of the selectivity in frequency and the limited underwater bandwidth.

More recent Seaweb [6] experiments have used hybrid TDMA/CDMA clusters with MACA-style RTS/CTS/DATA handshakes. This method of access is adequate for the stationary networks and not for the mobile networks or other networks that change quickly during the time. One of the most promising access methods is the CDMA, she has been evoked by Xie and Gibson in 2000 [4].

The met problem of CDMA is Near Far. In aquatic networks the method of CDMA access appears most promising, in which propagation delays will be reduced. The adaptation of MACA to the aquatic network looks to continue with Sözer and all [5] while adding the WAIT command in order to reduce collisions and to increase the efficiency of power.

In 2006, M.Stojanovic [7] proposed a specific access method to the aquatic environment inspired from FAMA, that is called slotted FAMA whose principle is to give out every packet (RTS, CTS, DATED or ACK) in the beginning of time slot to eliminate the asynchronous nature aspect of protocols and to eliminate data collisions.

Açar and Adams [6] studied in 2006 the TDMA centralized with control of power and adaptive debit. In 2006MOL 06 M.Stojanovic, purpose UWAN-MAC, Distance Aware Collision Avoidance Protocol DACAP [8], which is scalable for the changing number of nodes and the coverage area of the network.

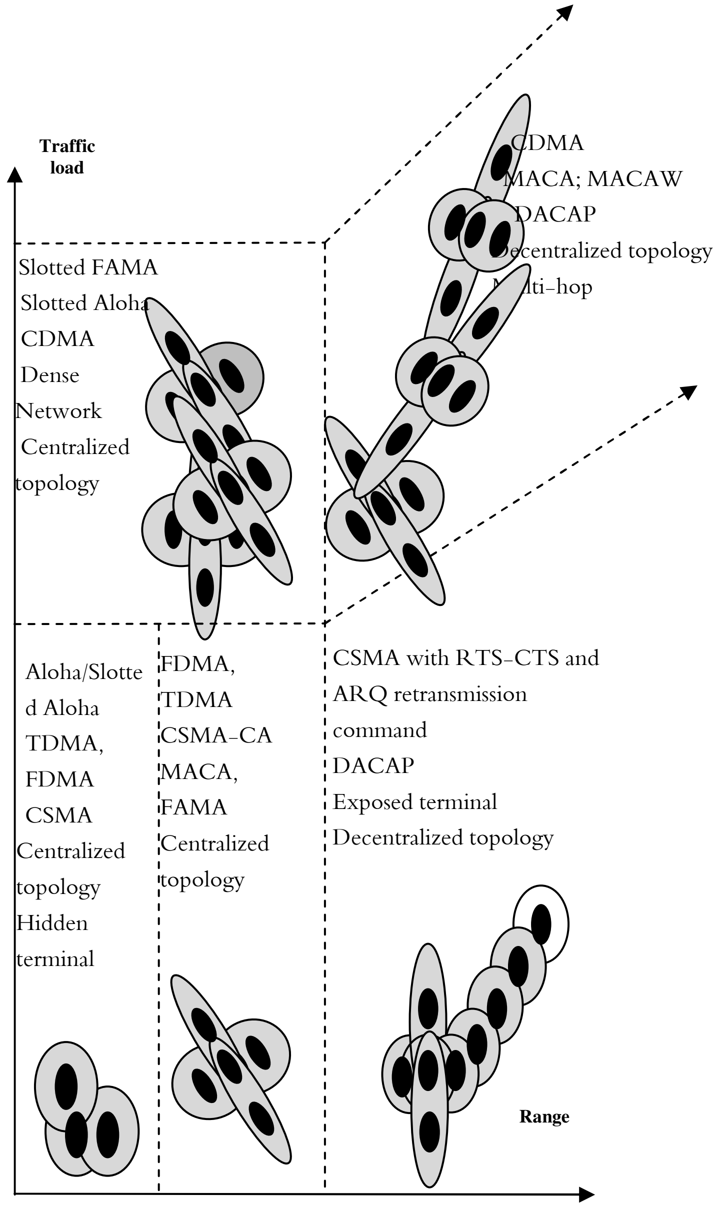

Fig.3. Taxonomy of underwater networking

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7 Floor Acquisition Multiple Access

The following table shows a characteristics survey of the main protocols for underwater communications:

TABLE II
SURVEY OF MAIN PROTOCOLS FOR UNDERWATER COMMUNICATION

Authors	Protocols	Characteristics
Smith and all 2006 [9]	CSMA/CA	-Performed well in term of latency -Low throughput
Seaweb'98 99 [10]	FDMA	- Improved performance on term of frequency-selectivity. - Not flexible and very inefficient in bursty traffic (due to limited bandwidth).
Seaweb 2000 [10]	TDMA-CDMA with MACA style RTS/CTS handshakes	- Evolution of seaweb spreading, improvement of the physical layer and the MAC layer. -Performed well in stationary and static nodes, but not in high dynamics network.
Xie and Gibson 2000[10]	CDMA	-Problem of Near far -Performed well in shallow water
Lapierre and all 2001 [10]	CSMA/CD	-Can not be used in a single channel packet radio network -Very difficult to construct a wireless underwater CSMA/CD system full duplex.
Salvà Garau and Stojanovic 2003 [11]	TDMA/CDMA	-Reduce the length of the TDMA slot, which increases the data rate. -Increase the probability of interference between the adjacent nudes.
Foo and all 2004 [10]	CDMA/MACA and MACAW	-Worst latency -It performs well in terms of packets received but at extremely high throughput.
Freitag and all 2005[12]	TDMA with less throughput	A central nude controls the network.
Molins and Stojanovic 2006[7]	Slotted FAMA	Limit the delay of propagation by addition of time slots.
Açar and Adams 2006 [10]	Centralized TDMA	Controlled power and adaptive throughput.
Rodoplu and Park 2006 [13]	UWAN-MAC	Adaptation of the S-MAC (MAC sleeping) in order to save the energy in the case of delayed aquatic sensors networks.
Borja Peleato and Milica Stojanovic 2006 [8]	DACAP (Distance Aware Collision Avoidance Protocol)	Scalable to the changing number of nodes and the coverage area of the network.

VI. Conclusion

UWSN bandwidth is constrained by the physical properties of the medium, for thus the existing terrestrial MAC solutions are unsuitable for underwater communication. In this paper a distributed Medium Access Control (MAC) protocols and access techniques for UW-ASNs are analyzed. Our contribution addresses the challenges in underwater network architecture and protocol design.

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Biographies

Nejah Nasri was born in Menzel Bouzaienne, Tunisia in 1980. He received the electrical engineering degree in 2004 and Master degree on electronics and telecommunication in 2006, both from National School of Engineers of Sfax, Tunisia (ENIS). He currently is working toward the Ph.D. degree in electronic and telecommunication at the same school. His research interest is to design of underwater wireless communication systems, especially the modeling and conceptions of RFID technologies for underwater applications.

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