



HAL
open science

Analysis of MAC protocols for Underwater Acoustic Data Networks

Hayat Doukkali, Loutfi Nuaymi

► **To cite this version:**

Hayat Doukkali, Loutfi Nuaymi. Analysis of MAC protocols for Underwater Acoustic Data Networks. VTC 2005 : IEEE vehicular technology conference, Stockholm, 30 mai - 1er juin, May 2005, Stockholm, Sweden. pp.1307 - 1311, 10.1109/VETECS.2005.1543520 . hal-02125124

HAL Id: hal-02125124

<https://hal.science/hal-02125124>

Submitted on 24 May 2019

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Analysis of MAC protocols for Underwater Acoustic Data Networks

Hayat DOUKKALI and Loutfi NUAYMI

Dpt Signal et Communication & Dpt Réseau et Services Multimédias

GET/ENST-Bretagne FRANCE

email:{hayat.doukkali, loutfi.nuaymi}@enst-bretagne.fr

Abstract—This paper presents a state of art of existing Underwater Acoustic Networks. We study specifically the Media Access Control (MAC) Protocol design of research work done in this field. A comparison of different protocols is presented according to several criteria: propagation delay, node connectivity and energy consumption. This comparison allows us to present some ideas for a new design of a MAC Underwater Acoustic protocol.

Keywords- Underwater Acoustic Network; MAC Layer; acoustic channel; TDMA; CDMA; Power control.

I. INTRODUCTION

Underwater Acoustic Networks constitute an important topic of interest for the offshore oil industry. It allows wireless communication between different submarine control vehicles and elements above the surface of the sea. Thus, the use of fewer physical links allows a lower cost in installing an oil platform. An example of the different nodes of an underwater acoustic network is illustrated in figure 1.

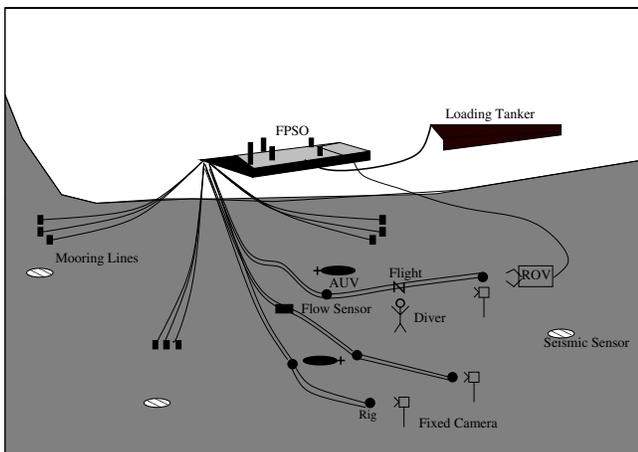


FIG. 1 –. Control elements of control constituting an underwater oil platform

We assume that we work with a depth of up to 700 meters.

The paper is organized as follows: section II presents the specific problem of the underwater acoustic channel.

In section III, we present some existing proposals for underwater acoustic networks. The comparison between these protocols based on some metrics is presented in section IV. Our ideas for a new underwater acoustic MAC protocol are detailed in section V, followed by a conclusion in section VI.

II. THE SPECIFIC PROBLEM OF UNDERWATER ACOUSTIC DATA NETWORKS

Sound propagates well in water because attenuation due to absorption and diffusion is much smaller than for electromagnetic waves. Thus acoustic waves constitute the best and, currently, the only way of underwater data transmission.

The underwater acoustic channel present analogies with the radio mobile channel with regard to propagation phenomena. The underwater channel is a multi-path and frequency selective channel. But the propagation speed of the acoustic wave under water is very low compared to the propagation speed of radio electromagnetic waves (ratio of $1/200000$): the propagation speed of acoustic signals is 1500 m s^{-1} under water, instead of the speed of light $c=3*10^8 \text{ m s}^{-1}$.

In the literature, the approach used to model these disturbances (signal fading and interferences) is the discrete multipath model that we used in [1]. The channel response is given by equation 1:

$$c(t, \tau) = \sum_{i=1}^N c_i(t) \delta(t - \tau_i(t)) \quad (1)$$

where N is the number of paths, c_i and τ_i are the attenuation and the delay of the channel respectively.

The main differences with the radio mobile channel which may be taken into account in the design of a data transmission protocol are:

- **Propagation delay:** the low propagation velocity in the aquatic environment increases the latency of transmission. For usual distances of the order of a kilometer (Km), the delay of propagation is about a second (s). This limits applications with strong temporal constraints and reduces considerably the load of the traffic on the network. For example, in

[2] and [3], the authors state that the Carrier Sense Multiple Access (CSMA) protocol does not work properly under these conditions.

- **Data rate:** very low compared to radio mobile communication. In underwater acoustics, the data rate cannot exceed some tens of kbits per second. This is due to the material constraints of acoustic transducers.
- **Frequency:** in underwater communication systems, the frequency band resources are severely limited. Long distance communication systems (a few tens of kilometers) are limited to frequencies of the order of a few tens of KHz. Systems operating at distances of a few meters can use frequencies of the order of some hundreds of KHz. This limitation of bandwidth resource is explained by the fact that the higher the frequency, the more significant the absorption.

III. MAC LAYER FOR UNDERWATER ACOUSTIC NETWORKS

A. The Network topologies

The three basic topologies existing for underwater acoustic networks are :

- **centralized topology:** communication between nodes pass through a central station. This topology is preferred for deep water acoustic networks [4][5][6]. One disadvantage of this architecture is that the network depends fully on the central station. Another problem is the difficulty of scalability.
- **single hop distributed topology:** this topology provides point-to-point links. The radio access protocol may be less optimal.
- **multihop topology:** each node has the possibility to communicate with any other neighboring node. This architecture covers a large area because the range of the network is determined by the number of nodes and not by the coverage of one node.

The protocol of [4][5] proposes several nodes per master node (base station) and proves that using multihop links, the system minimizes energy consumption. In [7], the authors propose a multi-cluster protocol over a multihop distributed topology. In [3], the authors propose a centralized dynamic architecture (possibility of adding or moving a node). The configuration of the topology is performed by the master node using Topology Discovery Message (TDM).

B. Multiple Access Techniques

Multiple access can be done using FDMA, TDMA or CDMA. The use of TDMA techniques needs precise synchronization between users. Moreover, it increases the latency of the system. Therefore, TDMA techniques are generally not suitable in the case of underwater communications. The authors in [4] propose using FDMA

but CDMA is also suitable. In [7], the authors use a combination of the two techniques: CDMA to communicate between clusters and TDMA inside each cluster (see below).

C. Media Access Protocol

In this section, we present some currently proposed MAC protocols for underwater acoustic data networks.

1) *Adapted MACA to underwater acoustic networks:* In [4][8], the authors propose a media access control protocol based on the MACA (Multiple Access with Collision Avoidance) protocol, which uses CTS-RTS-DATA exchange. Error detection is done using STOP&WAIT ARQ (Automatic Repeat Request): the source waits for an Acknowledgment before transmitting the following packet (see figure 2-a).

If after a specified time the source does not receive the ACK, it retransmits the packet until it receives an ACK. The source drops the communication after K retransmissions not followed by an ACK packet (see figure 2-b). Using this classical MACA scheme, energy consumption may increase in the case where the source repeats its request several times. To solve this problem, the authors of [4] propose adding a WAIT command (see figure 2-c), so the destination tells the source that it is busy and will send the CTS as soon as it can. To avoid deadlock problems (see figure 2-d), an assignment priority is added to packets directed toward the master node.

2) *A MAC protocol for multi-channel underwater acoustic environment:* The authors of [2], propose a multiple access protocol with different frequency channels. The purpose of this system is to transmit high data rate applications.

The frame transmission mechanism begins by detecting the candidate channel which can transmit the frame. Within these candidate channels, a selection of the longest idle channel is performed to define the transmitting channel.

The frame reception procedure manages the transmission of the ACK frame if there are no transmission errors, and the transmission of an NACK if there are errors after cancelling the received frame.

After the frame reception mode, the system returns to a carrier sensing mode, which calculates the idle time for each channel [2]. To our knowledge, this is the only paper that considers a multiple channel environment with dynamic channel allocation.

3) *A scalable centralized protocol for underwater networks :* in [3], the authors propose a centralized topology. This scheme reduces the propagation delay compared to the 4-way handshake mechanism (see Table I): the central station provides a dedicated transmission channel to each node and pre-computes all routes.

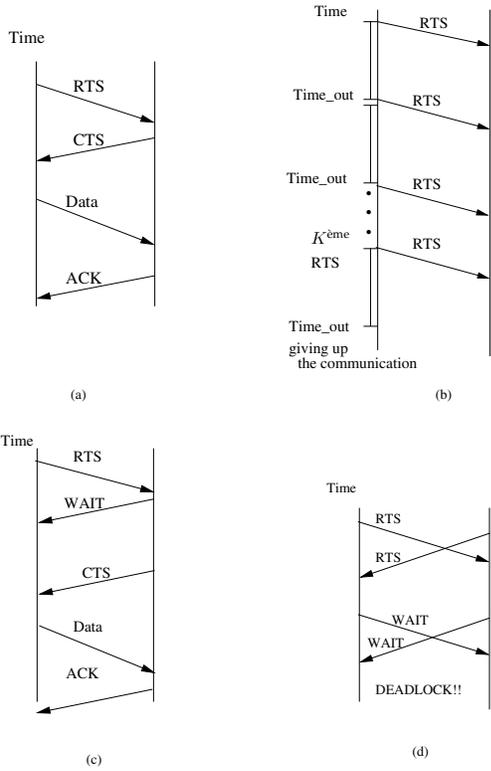


FIG. 2 – Adaptation of MACA protocol to underwater acoustic communications (based on [4])

The proposed protocol allows nodes to be added or removed dynamically. The master node configures periodically the network topology by transmitting Topology Discovery Messages (TDM). Topology discovery message propagation allows the master node to have complete information regarding membership of the network and each node’s immediate neighbors. A power control mechanism is integrated into the transmission of TDM.

4) *Clustering and CDMA/TDMA multiple access*: Work presented in [7] proposes a multi-cluster protocol for distributed ad hoc (no master node) underwater acoustic networks. Communication in each cluster is done using TDMA, which means that each node transmit during its assigned time slots. Allocation of time slots is carried out in the network initialization phase. In this phase, three main operations are carried out:

- division of the network into clusters;
- division of the frame into slots;
- assignment of CDMA codes to clusters.

A maintenance phase is needed due to node mobility. Communication between two clusters is performed using CDMA which allows the simultaneous use of slots across clusters (see figure 3).

CDMA is used by the assignment of orthogonal codes to clusters (adjacent clusters do not overlap). Thus, each

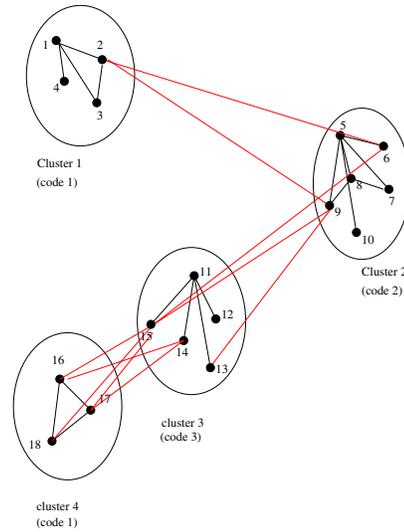


FIG. 3 – Example of a clustering network using CDMA with the reuse of code 1 by cluster 4 in addition to cluster 1

cluster has a code for transmission and each node from that cluster transmits using this code. The number of codes is limited and this limits the number of clusters. To solve this problem, authors in [7] propose to reuse code as in cellular networks (see figure 3). This technique of reusing code is possible because the acoustic signal fades due to distance.

The authors show that using this clustering concept, it is possible to achieve a more efficient use of network resources through the spatial reuse of resources (CDMA code reuse).

IV. COMPARISON

In this section, we compare the protocols mentioned in section III-C. These protocols are evaluated according to the following metrics:

- **Delay**: calculated as the difference between the time of a frame transmission and the time of its successful reception. An example of a simulation that provides some delay values in the case of 4-way handshake (with RTS/CTS) and 2-way handshake (without RTS/CTS) is presented at table I.

	Number of sent packet	Average delay
With RTS/CTS	50	1.09 s
Without RTS/CTS	50	0.84 s

TABLE I – Acoustic delay of transmission in a network of 8 nodes

This example illustrates the fact that the transmission of the RTS/CTS packet before each packet increases the delay significantly. These values are obtained using Network Simulator 2 (NS2) after its

Protocol	Principle	Delay (the average delay)	Energy consumption	Node connectivity	Comments
Sozer,2000 [4] [8]	<ul style="list-style-type: none"> Multi-hop distributed topology. Adaptation of RTS/CTS/DATA/ACK exchanges 	Considerable delay compared to a centralized network (due to transmission of RTS/CTS packet before each communication)	A calculation of the minimum power level which ensures reliability of transmission is performed during RTS/CTS exchanges.	The use of multi-hop topology in order to reduce energy consumption level allows us to limit the connectivity of each node to its two neighbors.	Absence of collisions by using the WAIT command which also allows preservation of battery power, but this results in increased delay of propagation
Yéo,2001 [2]	<ul style="list-style-type: none"> Multi-channel environment. Carrier sensing based on the use of idle-timer of each channel known by all nodes (no need for RTS/CTS) 	Delay equivalent to the case of a centralized network because carrier sense is done using the information of the state of the channel (flag and idle-time values) which is known by all nodes of the network	Absence of a power control protocol so there is no optimization of energy consumption.	The connectivity of each node depends on the number of its transmitting and receiving channels	Specific case due to multiple channels. Local information about the state of channels known by nodes.
Xie,2000 [3]	<ul style="list-style-type: none"> Centralized network around a master node. Possibility of adding and removing nodes. Topology control is done by periodically transmitting special messages (TDM). 	Smaller than the delay of the scheme of [4] (thanks to the absence of RTS/CTS packets).	The power is controlled during TDM exchange	The centralized scheme reduces the connectivity of nodes other than the master node	The centralized scheme is interesting in the case of small networks only (not scalable). Routing, power control and topology control information are managed by topology configuration messages.
Salva,2003 [7]	<ul style="list-style-type: none"> Grouping of nodes into clusters. Multi-hop distributed scheme. Use of CDMA/TDMA . 	The delay depends on the value of the transmission range and of the number of nodes (direct transmission of CDMA/TDMA frame).	Adjustment of the power level in order to reach other nodes. Absence of optimization of the transmitting power level.	The concept of clustering as defined by [7] ensures maximum connectivity between nodes.	The clustering concept allows us to achieve a more efficient use of network resources through spatial reuse of resources (CDMA code).

TABLE II –
Comparison between different MAC protocols for underwater acoustic networks

adaptation to the context of underwater acoustic channel (by modifying the value of the propagation speed, frequency and data rate). The simulated network is composed of 8 nodes. We consider TCP traffic between two nodes separated by a distance of 100 m and other TCP traffic between two other nodes separated by 80 m. Each node transmits at the power level $p_t = 0.313W$ and the range of the nodes for this power level is equal to 100 m. For the two scenarios (transmission with and without RTS/CTS), we transmit 50 TCP packets.

- **Energy consumption:** this equals the total energy used for frame transmission.
- **Node connectivity:** defined as the percentage of the transmitter’s neighbors that successfully receive a frame.

Table II summarizes the comparisons between the MAC underwater acoustic networks protocols presented above.

Comments concerning each protocol are given.

V. COMMENTS AND PROPOSAL

In this section, we present our design of a new MAC underwater acoustic protocol based on a comparison between existing protocols.

Regarding the mobility of the nodes of the network (see figure 1), our work considers protocols similar to those presented in [4][7][3]. The MAC protocol of [2] being more suitable in the case of fixed nodes. The centralized scheme presented in [3] has the disadvantage that it cannot work properly for a large number of nodes.

We recommend a CDMA/TDMA clustering scheme for the following reasons: first, the cluster algorithm is robust with regards to changes of topology (adding or removing nodes); second, the use of CDMA techniques allows one to combat interference and multi-path fading; finally, such a scheme provides spatial reuse of resource

and this is important in the case of the limited bandwidth of the underwater acoustic channel.

Our proposal is the integration of a power control protocol. The advantage of a power control protocol is that it extends the battery life of stations and increases the traffic capacity of the network. The formation of clusters may then be based on the available power levels. Based on these power levels, we can build up clusters where minimal transmitted powers are used (see figure 4).

As in [7], we propose to use CDMA for inter-cluster communication. More details of the proposed protocols and its performance are provided in [9].

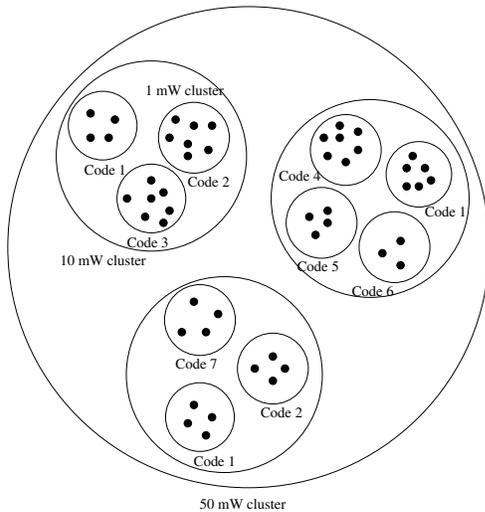


FIG. 4 – Assignment of CDMA codes using three power levels 1mW, 10mW and 50mW.

VI. CONCLUSION

In this paper, we study the design of a MAC protocol for underwater acoustic networks. The acoustic channel used has some specific aspects with regards to the wireless channel: long propagation delay, limitation of bandwidth and frequency, etc. We recall these aspects and then briefly describe some existing proposals for underwater acoustic networks. These proposals are analyzed and compared.

Interesting conclusions can be made based on these comparisons. We suggest the design of a new MAC protocol for underwater acoustic networks based on the idea that the integration of power control in a clustered MAC protocol may solve the problem of limited battery power while improving the performance of the network. Future work [9] will give the details of this new protocol and analyze its performance.

ACKNOWLEDGMENT

The authors would like to thank Ms Janet Ormrod for her helpful comments.

REFERENCES

- [1] H. Doukkali and S. Houcke, "Cdma based approach for transmit diversity over frequency selective fading channel," *The second International Symposium on Image/Video Communications over fixed and mobile networks*, 7-9 July 2004.
- [2] Jin-Ki Yeo, Young-Kon Lim, and Heung-Ho Lee, "Modified mac(media access control) protocol design for the acoustic-based underwater digital data communication," *IEEE*, pp. 364–368, ISIE 2001,Pusan, KOREA.
- [3] G. Xie and J. Gibson, "A networking protocol for underwater acoustic networks," *CS Department, Naval Postgraduate School*, December 2000.
- [4] E. M.Sozer, M. Stojanovic, and J. G. Proakis, "Underwater acoustic networks," *IEEE journal of oceanic engineering*, vol. 25, no. 1, pp. 72–83, January 2000.
- [5] E. M.Sozer, M. Stojanovic, and J. G. Proakis, "Design and simulation of an underwater acoustic local area network," *Proceeding IEEE, Opanet 99,Washington*, August 1999.
- [6] E. M.Sozer, M. Stojanovic, and J. G. Proakis, "Initialisation and routing for ad hoc underwater acoustic networks," *Proceeding IEEE, Opanet 00,Washington*, September 2000.
- [7] F. Salva-Garau and M. Stojanovic, "Multi-cluster protocol for ad hoc underwater acoustic networks," *OCEANS 2003. Proceeding*, vol. 1, pp. 91–98, September 2003.
- [8] J. G. Proakis, E. M.Sozer, M. Stojanovic, and et al., "Shallow water acoustic networks," *IEEE communications Magazine*, pp. 114–119, November 2001.
- [9] H. Doukkali and L. Nuaymi, "Clustering and power control for underwater acoustic networks," *Submitted to the 16th Annual IEEE International Symposium on Personal Indoor and Mobile Radio Communications*, 11-14 September 2005.