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Cross-Layer Design For Energy-Efficient In Wireless Underwater Communication: Acoustic Frequency IDentification Case Study

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Abstract

Thanks to the recent developments on communication techniques, micro-technology and on digital electronics, Underwater Wireless Sensor Networks (UWSNs) are being employed in several types of underwater applications such as wireless identification named Acoustic Frequency Identification (AFID)[1][2]. In this research, we are trying to adapt concepts of wireless acoustic identification to the difficult underwater environment with its hard constraints especially absence of high bandwidth communication (no radio).So, there is a critical parameter in UWSN making challenge because it determines how longer sensor nodes and the entire networks would remain functional. However, in these types of Networks, node's battery presents a limited energy resource and network lifetime is related to the energy consumption by a node. Thus, in this paper we will propose some contributions and cross-layer design to prolong the AFID network lifetime.

Keywords: *UWSNs, AFID, network lifetime, energy consumption, cross layer.*

1. Introduction

Acoustic Frequency IDentification sensor networks are formed by a large number of sensor nodes distributed over an ocean geographical area named AFID sensor; they are designed to communicate with different underwater objects (Marine vessels, Submarines, some types of fish, etc.) and to communicate with the reader through acoustic links [1][2][3].

These networks could be rapidly deployed and need a very short period to be established and then to reach data gathering stage. Also, successful underwater navigation is not only crucial for any type of mission, it is also an interesting application for multi-vehicle scenarios as each vehicle has the possibility to improve the knowledge about its own position by exchanging information with AFID sensors fixed in the bottom of see(figure 1)[4].

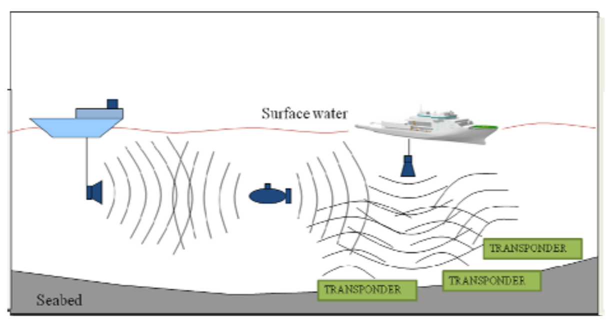

Fig. 1 Typical architecture of AFID sensors [4]

Unlike traditional wireless networks, UWSN are built to be deployed as an autonomous network without any type of network administration to control data transmission in the common acoustic link. Gathered information, by AFID sensor nodes, are routed through the network to AFID reader having more powerful units in terms of, energy, acoustic unit range and computational operations. Sink's job is to collect data from AFID sensor nodes and then transmit them to the user, and also can serve as gateway for interconnection to other networks like UWSN. (Figure1).

Underwater Wireless Sensor Networks (UWSNs) research has predominantly assumed the use of a portable and limited energy source, viz. batteries, to power sensors [5]. Without energy, an acoustic sensor is essentially useless and cannot contribute to the utility of the network as a whole. Consequently, substantial research efforts have been spent on designing energy-efficient networking techniques to maximize the lifetime of UWSNs [6]. However, AFID sensors are required to operate for much longer durations (like years or even decades). This paper surveys related research and discusses the challenges of cross layer designing networking for such AFID networks.

2. Underwater AFID Architecture

Underwater AFID node is made up of 3 principal units and a power unit (Figure2) [7]:

-Acoustic sensing unit: consists of hardware devices responsible for detection of signal from underwater reader and transmitting data from transponder to the reader. In this sensing, an analog to digital converter is required to convert acoustic signals to digital signals comprehensible by the processing unit.

-Processing unit: it consists of a microcontroller unit (MCU) that controls the functionality of other units and components and it is responsible for data processing. Data are temporary stored in an integrated memory (RAM).

-Communication unit: underwater nodes use acoustic wave. This unit is the first responsible unit for energy consumption.

-Power supply: it is a battery in general and it has a limited energy resource. The battery is responsible for energy supply for all units of the underwater node but it may be very difficult and sometimes impossible to change or to recharge it; for this reason, it's very important to have strategies for energy conservation.

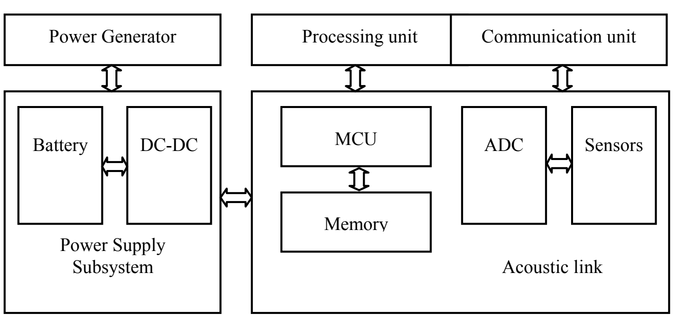

Fig. 2 Typical underwater transponder architecture

To perform some specific applications transponders nodes could be equipped with read write memory or a power generator. These additional units make the node bigger and more expensive.

AFID sensor networks can be more and more deployed in a wide variety of underwater applications for gathering information in order to develop wireless underwater identification and control. These AFID networks with intelligent autonomous sensors are also powerful in military, surveillance and security applications as underwater detection and tracking systems [8].

AFID sensors can be used for ocean surveillance and underwater security. So, this can be applicable around ships or in entrances of ports. Also, AFID sensor which act as beacons are fitted to aircraft to allow their location in the event of a crash in the sea. To improve the quality of our lives, researches are concentrating in developing AFID networks for many underwater applications and to achieve the full potential of these networks there are a lot of challenges and problems to be confronted.

3. Problems Statement For AFID Network Establishment

3.1 Challenges for establishing an AFID Network

Underwater wireless communication is characterized by high level of noise. So, Man-made and natural noises, animal or environmental (waves, rain), can interfere with good acoustic signal. To resume, this section describes the main problems for the establishment of AFID network.

- Physical constraints [9][10]:
  - The bandwidth of acoustic communications is relatively low (0 400 KHz).
  - Low throughput (less than 50 kbps)
  - Absorption phenomenon is the fundamental limitation of maximal frequency
  - limited, range-dependent bandwidth
  - time-varying multipath
  - low speed of sound (1500 m/s)
  - Long propagation delay
  - noise problems

-Energy consumption[10][11]:

Waste of energy is the critical parameter for UWSN because of its limited resources in which we cannot profit from energy solar to recharge battery.

Energy efficient communication is a key requirement of energy-constrained underwater sensor networks (UWSNs). In this paper, we present a solution which is conventionally used to improve reliability in AFID networks, it can be employed to reduce energy consumption and preserve a reasonable level of data reliability.

3.2 Waste of energy factors

Although energy is necessary for unit's function's and it is needed for reception or transmission of acoustic signal or energy required for microcontroller to store data there are also other sources of energy waste in UWSN.

In physical layer waste of energy is due to the bad choice of physical parameters such as optimal frequency [12][13]. So, as it is shown in figure 3, saving energy is based on the finding of optimal frequency for underwater communication.

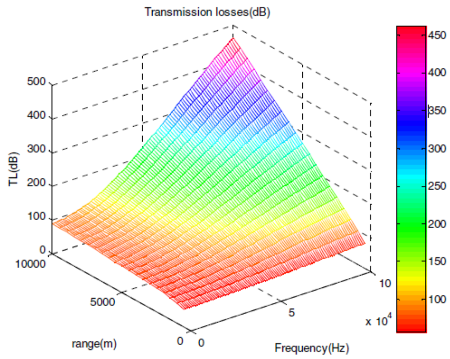

Fig. 3 Transmission losses versus frequency

This curve confirms that the transmission losses increase with frequency and distance between readers and transponders.

Also, in UWSNs, one of the main factors which cause low event reliability and energy consumption is the techniques of access to the medium [14][15]. So, current UWSNs protocol designs are largely based on a MAC layer approach. Thus, MAC issues are designed and operated independently. We will focus on energy aware MAC (Media Access Control) layer protocols for wireless underwater networks.

The most important sources of energy consumption in the MAC layer are [15][16][17]:

- Idle listening: a node does not know exactly when it will receive information from other nodes; it should be ready for reception by listening to the underwater channel. Lost information has to be retransmitted.

- Overhearing: when a sensor node is listening to the radio channel it can receive parquets that does not belong to it. Energy is wasted for reception and processing.

- Overmitting: when a node transmit a message to another node that it is not ready for reception this message will be lost.

- Collisions: they are the first cause of waste of energy and happened when two nodes transmit at the same time. In fact, the retransmission of data demands energy.

- Overhead: we don't transmit only user's data in the radio link but also many kinds of data necessary for the control of communication and for network management. These overhead must be relatively shorter than user's data to not affect the throughput.

4. Contributions For Saving Energy In AFID Networks

Underwater Network lifetime is the important criteria when evaluating AFID Network and as we know it depends on the energy consumption of the node unit's. This is related to minimize and optimize energy dissipation in every node of the network. Our approach is based on the cross-layering design in which MAC and physical layers should be investigated together.

Figure 4 shows the major levels of energy saving for UWSN [4].

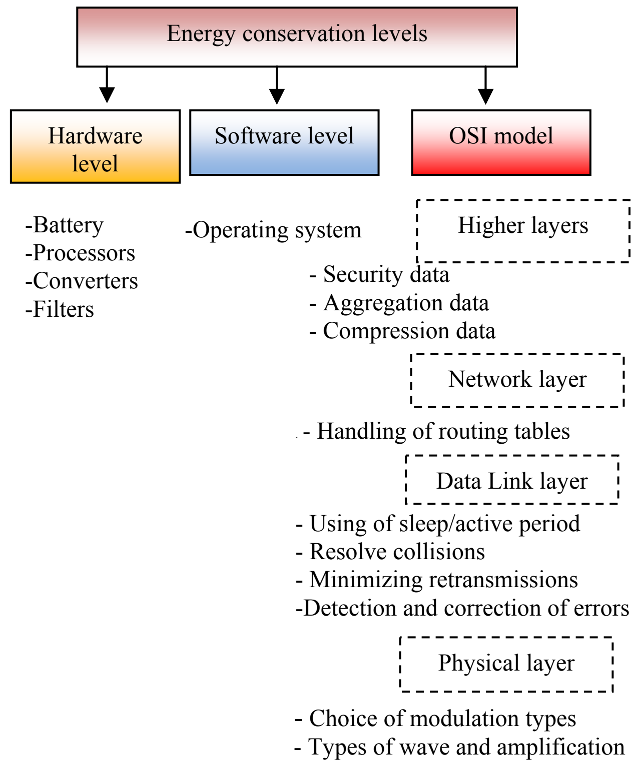

Fig. 4 Level of Optimization energy [4]

As illustrated in figure 4, there are many levels to reduce energy consumption. However, in hardware and software levels, energy consumption is very limited and continued to decrease with the progress of microelectronics. For this reason, a careful design of all layers of OSI model is required.

For underwater wireless communication systems energy consumption is linked to the characteristics of communication media. Several studies have been developed in this field in order to reduce energy consumption. They showed that the physical layer and MAC layer represent the relevant sources of energy consumption.

In the physical layer we must make a critical choice of module. So, the energy consumption in underwater

acoustic networks is due especially to the bad choice of signal frequency. In the MAC layer saving energy essentially amounts to the choice of access methods to minimize the numbers of retransmissions.
In this work, cross-layer optimization strategies consist on determining the optimal way to combine the most promising solution in physical and MAC layer to obtain the most efficient network solution.

4.1 Physical layer solution

In this subsection, we discuss the relationship between transmission distance and bandwidth. Also, we introduce the frequency allocation methodology that we will optimize energy consumption. The underwater attenuation level is given by the expression [18]:

$$A(r,\ f) = 20 \times \log(r) + a(f) \times r \quad (1)$$

With r is the distance between emitter and receiver, f is the central frequency and a(f) is the absorption coefficient proposed by Wong[18]:

$$a(f) = f^2\left(2{,}692\ .10^{-13} + \frac{7{,}858\ .10^{-2}}{f^2 + 1{,}226\ .10^{10}} + \frac{1{,}481\ .10^{-4}}{f^2 + 1{,}522\ .10^{6}}\right) \quad (2)$$

From these equations we note that the attenuation is directly proportional to the distance between the transmitter and receiver. Also, we note that attenuation varies with frequency. As a result of simulation figure 5 present the gain of signal for different distances versus frequency. From these curves, the effective bandwidth is generally estimated as the width of the receiver's channel pass band between the 3dB points above and below its center frequency of operation.

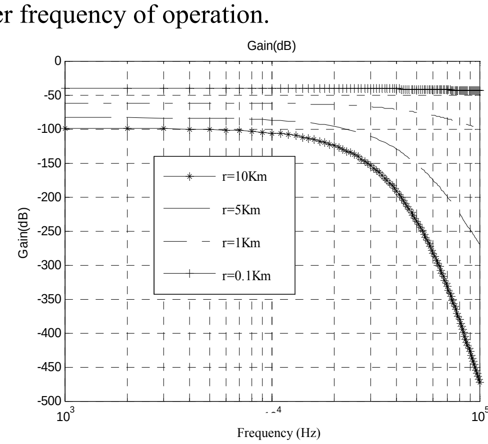

Fig. 5 Gain (dB) for different ranges depending on the frequency

Table 1 summarizes the bandwidth (-3dB) in the wireless transmission for various underwater range.

TABLE 1:
BANDWIDTH DEPENDING ON RANGES

ranges(Km)	Bandwidth (KHz)	Attenuation (dB)
5 à 10	5 à 10	<88
1 à 5	10 -25	<78
0.1 à 1	25-100	<61
≤0.1	≤100	<41

To minimize transmission losses and subsequently energy consumption we choose to use low frequency for long range.
According to heavy surveys that establish reliable underwater communication systems need to take into account optimal design parameters that must be guaranteed. Among these parameters we find the carrier frequency, the power required, the operational range and the desired Signal noise ration SNR.
So, optimizing underwater communication is essential to evaluate its performance in terms of signal to noise ratio (SNR).Wireless underwater communication efficiency (measured in terms of SNR) improves dramatically when operating near the optimal frequency.
Using the expressions of the attenuation A(r,f) and power spectral density(PSD) of noise N(f), we purpose to evaluate the optimal frequency that yields the best signal to noise ratio(SNR) when it emits a signal power P.
The SNR (r, f) can be expressed by [19]:

$$SNR(r,\ f) = \frac{P}{A(r,\ f) \times N(f) \times \Delta f} \quad (3)$$

Δf is the noise bandwidth of the receiver (a narrow band around the frequency f). The product A(f,r).N(f) represents the frequency dependent part in the expression of the SNR.
Figure 6 illustrates the variation of factor 1 / A (r, f) N (f) versus frequency at different distances.
For each transmission distance, it exists an optimal frequency f_0 in which a maximum SNR is achieved [20]. Figure 6 and table 2 shows the optimal frequency as a function of distance for which we have the maximum ratio of relative SNR.

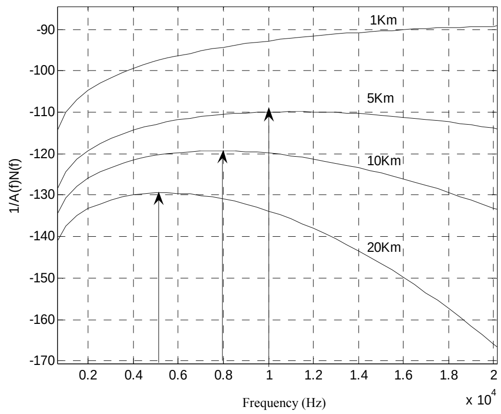

Fig. 6 Relative SNR versus frequencies and distances

TABLE 2:
OPTIMAL FREQUENCY VERSUS DISTANCES

Distances (Km)	Optimal frequency (KHz)
1	25
5	10
10	8
20	5

The modeling and simulation work realized aim to specify physical parameters needed to get wireless underwater communication characterized by low level of energy consumptions. The simulation results obtained are consistent to results obtained by the IEEE Oceanic [21] [22](table 3).

TABLE 3:
COMPARISON OF RESULTS

	IEEE'10[22]	IEEE'00[21]	Our results
Range (Km)	5		
Attenuation (dB)	78	--	78
Bandwidth (KHz)	≤9	--	≤10
Optimal frequency (KHz)	~9	--	~10
Network topology	--	Multi-hop	Multi-hop

4.2 MAC protocol solution

The major challenge for the development of underwater wireless network is to find a MAC protocol that can support the constraint of underwater environment. MAC protocol for UWSN should find compromise between three major factors: latency, energy-efficiency and auto-configuration. After a heavy bibliographic study we notice the presence of 3 types of protocols used underwater communication. The table 4 shows a comparison between the most of them [23][24][25][26].

TABLE 4:
COMPARATIVE STUDY OF THE MAIN PROTOCOLS USED FOR UNDERWATER COMMUNICATION

Types	Reservation			Contention	Hybrid
Protocols	TDMA	FDMA	CDMA	CSMA/CA	SMAC
complexity of implementation	×	×	×		
Flexibility to the number of nodes			×	×	×
Energy Efficiency	×				×
High data rate	×	×	×		

The reservation based Mac protocols are characterized by a low level of energy consumption by reducing the numbers of retransmissions due the message collisions. In other hand reservation MAC protocol are not flexible for the add or suppression of node. Also, deployment of the network is more complex. Contention MAC protocols are suitable for dense network, an acceptable level of complexity and they are flexible for different topology. But, these protocols are characterized by high level of energy consumption [27] [28] [29].

Finally, hybrid protocols combine the advantages of contention and reservation of protocols. So, these types of protocols are characterized by a low level of complexity, energy efficiency and flexibility to the number of nodes [30][31].

Based on this comparison we notice that, a SMAC protocol is promising solution for AFID network. SMAC is a slotted energy-efficient medium-access control (MAC) protocol designed to reduce energy consumption in wireless sensor networks. This protocol intends to make the consumption of the limited energy resources of the battery more efficient by using three principal techniques: periodic listen and sleep, collision and overhearing avoidance and message passing.

4.3 Modified SMAC

To minimizing complexity of implementation and since the AFID network is a centralized topology it's not necessary to use packet of synchronization. The modified SMAC is characterized by a low complexity of implementation. Modified S-MAC is a new version of the original S-MAC. This protocol is based on the same approach for energy conservation; the only difference is that it is not necessary to use mechanism of synchronization between nodes. This approach reduces latency caused by synchronization algorithm. Figure 5 describes the principal of modified SMAC implementation.

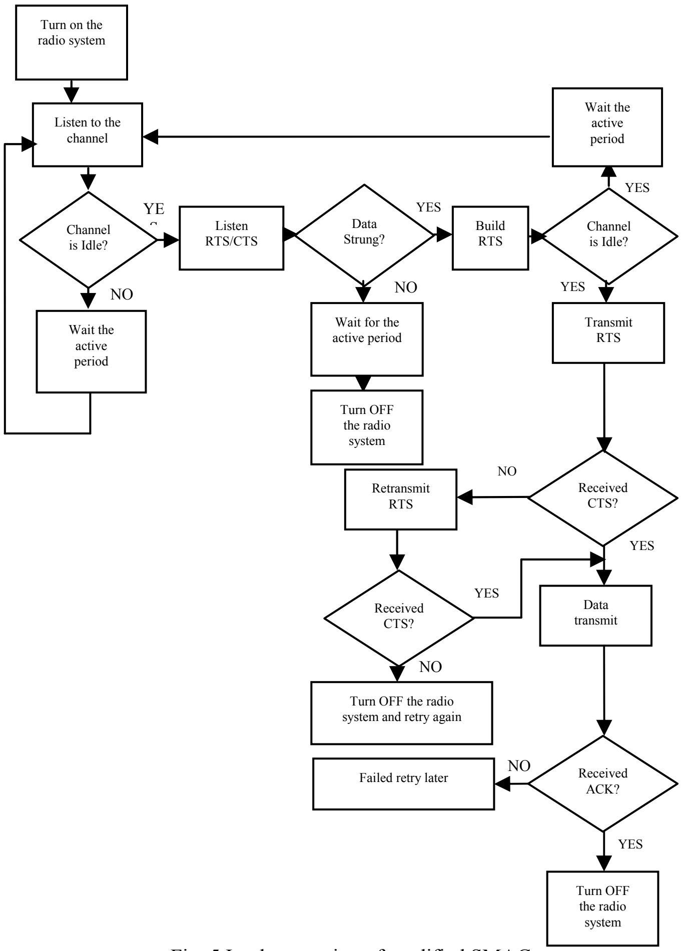

Fig. 5 Implementation of modified SMAC

By this way, AFID nodes are able to immediately pass the data to the readers without synchronization. When the node does not receive anything (RTS or CTS packet) during the listening time, it will go back to sleep until it's next scheduled listen period.

5. Simulations Result's

Simulators represent a good solution for economizing time and money before the establishment of a communication network. Thus, simulators prove result's punctuality but this differs from one to another simulator but it is not so easy to make a choice when there is a multitude of simulators. In fact, all depends to the particularity of each application that scientist make their one choice. Many studies have been trying to do a comparative study between most important simulators (J-SIM, NS-2, OPNET, GloMoSim, ATEMU, etc.) in order to determine what are simulating tools which make possible testing and evaluation of new communication protocol before its deployment.

For our application we use NS2 simulators for a reasons of documentation and because it contains libraries to generate different functions (topology, traffic routing MAC…), graphical tools to facilitate interpretation (Xgraph) and visualization (Networtk animators) results. The goal now is to evaluate the behavior of MAC protocols based on throughput and energy consumption metrics. We present a simulation of a star topology with different types of protocols' hybrid (Modified SMAC), reservation (TDMA) and contention (CSMA/CA). We consider the total energy consumed by the entire network as a performance metric for AFID network.

Figure 7 shows the centralized topology of AFID network implemented in NS2.

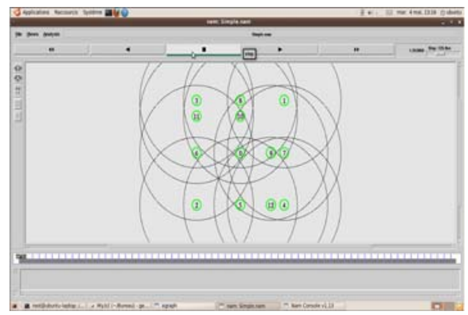

Fig. 7. Scenario of simulation

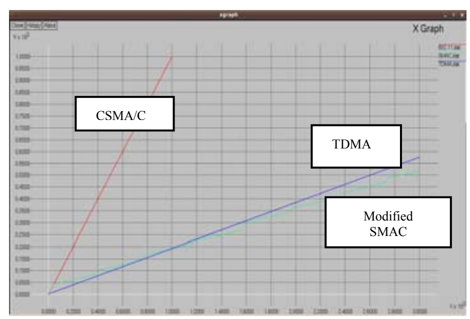

Fig. 8. Energy consumption versus simulation time for the three protocols, TDMA, CSMA / CA and modified SMAC

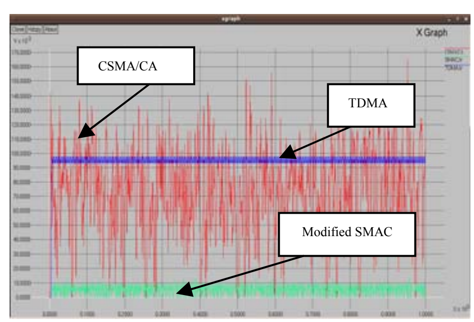

Fig. 9. Date Rate of: Modified SMAC, CSMA / CA and TDMA

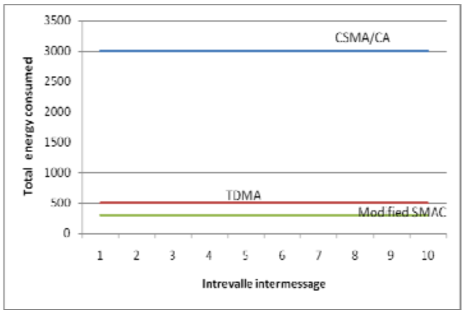

Fig. 10. Energy consumption for different traffic

Figure 8 shows that energy consumption increase linearly with simulation time for three protocols in question (TDMA, CSMA/CA and modified SMAC). The result of simulation justify the benefits of using hybrid modified SMAC in terms of energy consumption.

Figure 9 shows that TDMA and CSMA/CA are characterized by high date rate compared to modified SMAC. So we can notice that modified SMAC is more suitable for low data rate this is the case of AFID network. From figure 10 we see that depending on the traffic load flowing through the network, the modified SMAC has the best performance in terms of energy consumption. This low energy consumption due to the fact that this protocol mix characteristics of both TDMA and CSMA/CA (reservation and contention) while exploiting the advantages offered by each of them.

6. Conclusion

We addressed the problem of power-efficient communication in underwater channel with objective of optimizing energy consumption in physical and MAC layers. Work in physical layer is oriented towards the study of different physical characteristics of the underwater channel and AFID system. The level data link work is oriented to present efficient communication protocols for AFID Networks.

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