A Survey of Existing Medium Access Control (MAC) for Underwater Wireless Sensor Network (UWSN)

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Abstract—Underwater wireless sensor networks (UWSN) consist of a certain number of sensors that interact to send the sensed data to the sink node and perform collaborative task. Most UWSN choose acoustic as a communication medium for wireless transmission. However, electromagnetic waves are also offer a great merit in special underwater environment such as shallow water. UWSN is significantly different from terrestrial sensor networks in many aspects such as mobility of sensor nodes due to water current, propagation delay and propagation loss. These distinctions feature of underwater sensor network pose many new challenges for delivering information from sensor nodes to sink node effectively in UWSN. To achieve reliable data transfer in underwater sensor network scenarios, a new event MAC protocol need to be developed to provide energy efficient and reliable upstream data transfer.

Keywords- Underwater wireless sensor network, MAC protocol, transport protocol, RF communication

I. INTRODUCTION

Underwater wireless sensor network (UWSN) has received growing interest recently. In terrestrial sensor networks, for critical application, reliable data transfer is demanded in UWSN. Different applications have different reliability requirements. Thus, data reliability is one of the most important requirements in UWSN. Therefore, assuring reliable data delivery between the sensor nodes and the sink in UWSN is a challenging task because UWSN are subject to limitations and constraints of the real world and interact closely with the physical environment in which they reside. To design an efficient reliable data transfer protocol, energy efficiency is the issue.

Most existing work on wireless underwater networking targets deep and oceanic environments which led to design of power and expensive underwater communication hardware [1]. But, this project will be focused on shallow fresh water because there has been some interest recently on fresh water such as river, lake and others. The needs of reliable data transfers in shallow fresh water are very important in the biological, social and economic point of view.

There are many type of medium for wireless transmission in UWSN such as acoustic, radio frequency (RF) electromagnetic wave and optical wave. Most of the UWSN choose acoustic as a medium for wireless data transfer. However this project focuses in shallow underwater environment which is suitable for RF electromagnetic wave wireless transmission. Studies show that the acoustic transmission is not suitable for shallow water because it yields poor performance. This is due to the turbidity, ambient noise, salinity gradients and pressure gradient [2]. On the other hand, optical communication is usually unviable due to the frequent high turbidity of the water and the high variability of the water [3].

The need of reliable data transfers in shallow fresh water is very important in the biological, social and economic point of view. That is the main reason why this project focused on shallow fresh water such as river, lake and others. In fresh water environment, the water is of the turbid. The best technique is to use is rado frequency electromagnetic wave because radio communication represent a viable low lost alternative for creating shallow water short distance.

In this paper, the characteristics of underwater RF communication are reviewed in section II and the factor that influencing the design of underwater protocol are presented in section III. The related works of reliable MAC protocols for UWSN are reviewed and summarized in section IV. Finally, in section V, we describe some future research directions of protocol in UWSN.

II. UNDERWATER RF COMMUNICATION

Underwater sensor networks have many applications potentially in oceanographic data collection, water quality monitoring and surveillance purposes. Underwater communication is quite a challenging area to explore because it is different compared to the terrestrial environment. The main differences between underwater and terrestrial are medium of signal propagation, cost and also power battery consumption.

Underwater environment can be divided into two categories of depths, which is shallow water and deep water. In oceanic literature, shallow water refers to water depth



lower than 100m, while deep water is used for deeper oceans. Deep water environment is more challenging compared with the shallow water. But shallow water has other challenges due to the multipath propagation. In particular, among all marine environments, one of the most rapidly and directly affected by human activities is the shallow water coastal environment. It is ecological significance and makes it a critical management and monitoring target [3].

From the literature, the performance of various underwater communication technologies in shallow water environment suggests that both acoustic and optical communication may not suitable in this environment. Regarding acoustic communication, the low depth of the water enhances the phenomenon of multipath propagation, thus requiring a considerable level of signal processing in order to achieve reliable communication. While optical communication is usually unviable due to the frequent high turbidity of the water in these environments and high variability it can present [3].

Although electromagnetic waves outperformed in deep, long distance communication, communication represent a viable low lost alternative for creating shallow water short distance links. Comparing to acoustic and optical wave technologies. RF electromagnetic technology allows flexible deployment of UWSN for monitoring applications. RF electromagnetic has many advantages compare to others. First, both acoustic and optical waves cannot perform smooth transition through the air-water interface. But electromagnetic wave scan cross water-to-air boundaries easily which is its signal follows the path of least resistance. Second, electromagnetic transmissions are tolerant to turbulences that are caused by tidal waves or human activities. Third, electromagnetic frequencies offer higher bandwidth than acoustic technologies. The typical bandwidth range for acoustic is up to 20kbps, while radio frequency bandwidth can be up to 100Mbps [4].

A. Electromagnetic in Freshwater and Seawater

Due to the fact that electromagnetic (EM) field propagated differently in freshwater and seawater, EM in these two types of media are detailed as follows.

Freshwater is a low-loss medium. The propagation speed can be expressed as [7]

$$c \approx \frac{1}{\sqrt{\varepsilon \mu}} \tag{1}$$

where \mathcal{E} is dielectric permittivity and μ is magnetic permeability. The dielectric permittivity can be expressed as a product of the permittivity in air, $\varepsilon_o (= 10^{-9}/(36\pi))$, and the dimensionless relative permittivity, ε_r . Since ε_r for water is about 81, the speed of underwater EM waves is slowed down by only a factor of 9 of the speed of light in

free space. Clearly, this speed is still much faster than acoustic waves, by more than 4 orders of magnitude and it poses no problem in channel latency [8].

The absorption coefficient, α for EM propagation in freshwater can be approximated as [7]

$$\alpha \approx \frac{\sigma}{2} \sqrt{\frac{\mu}{\varepsilon}}$$
 (2)

where σ is the electric conductivity. The absorptive loss is essentially frequency-independent, and EM waves can literally propagate through freshwater body. However, the problem in using EM waves for communication in freshwater underwater sensor network is the antenna size. The big antenna size of an EM transmitter is unpractical for the deployment of underwater sensor network [8].

Seawater medium characteristic is in contrast with the freshwater. Seawater has high loss medium. The electric conductivity σ is about two orders higher than that of freshwater. The higher conductivity in seawater is mainly due to the cumulative increase of total dissolved solid (TDS) concentration in oceans, such as the great salinity. In highly conductive medium, both the propagation velocity and the absorptive loss of EM waves are functions of carrier frequency [8]. The propagation speed of EM waves in seawater can be expressed as [7]

$$c \approx \sqrt{\frac{4\pi f}{\mu \sigma}} \tag{3}$$

While the absorption loss can be approximated as [7]

$$\alpha \approx \sqrt{\pi f \mu \sigma} \tag{4}$$

The conductivity σ in seawater is about 4S/m and the electric permittivity ε is $81\times10^{-9}/(36\pi)$. These value yield a transition frequency of about $4\times36\pi\times10^{9}/(2\times81\pi)=888MHz$. This means that if a carrier working on the frequency of 10MHz in seawater, which is much lower than seawater's transition frequency, then the EM field is not a wave anymore and it rather behaves like a diffusion field. Therefore, EM communication in seawater is literally unpractical when using classical approaches based on wave propagation [8].

III. FACTORS INFLUENCING THE DESIGN OF UNDERWATER PROTOCOL

Communication channels in shallow water have numerous imperfections due to many factors including shipping noise, multipath, water motion, density gradients and the non-homogeneity of the water due to the particles of solid or gaseous matter. Of these factors, time-varying multipath propagation and non-Gaussian noise are the two major factors that limit communication in shallow water [9]. In shallow water, propagation occurs in surface bottom bounces in addition to a possible direct path. Moreover, channel characteristics vary with time due to random signal

fluctuations. These include surface scattering due to waves, which is the most important contributor to the overall time variability of the shallow water channel [9].

The depth of water is a serious factor impacting UWSN. The factor that influent the underwater communication as follows:

- Transmission loss: Attenuation and geometric spreading are the main concern of the transmission loss [10]. The attenuation mainly refers to the energy absorption or conversion into heat. Attenuation of radio waves in water increases both with increase in conductivity and increase in frequency. The geometric spreading can also spread the energy of signal because of the expansion of wave fronts.
- Multipath: The propagation in multipath can severely degrade the signal. The link configuration such as horizontal channels characterization determines the geometry of multipath [10].
- Noise: Environment noises include man-made noise and ambient noise. Man-made noise mainly refers to machinery noise like pumps while natural noise refers to seismic and biological phenomena can cause ambient noise [10].
- Propagation delay and delay variance: Large propagation delay and high delay variance can be reduced the throughput of the system [11].

IV. NETWORK MODEL IN UWSN

A network model between two nodes in UWSN environment is shown in Figure 1. The network is composed of underwater sensor nodes, underwater sink node and surface sink node. The underwater sensor nodes are deployed to the bottom of the monitored environment such as ocean and river. While underwater sink nodes take charge of collecting data of underwater sensor deployed on the ocean bottom and then send to the surface sink node. Lastly, surface sink node is attached on a floating buoy is attached on a floating buoy with satellite, radio frequency (RF) or cell phone technology to transmit data to shore in real time.

The depth of the fresh water for this research is lower than 100 m while the range between two nodes is about 6m until 20m for short range communication.

V. MAC PROTOCOL

The MAC layer has the objectives of managing and controlling communication channels which are shared by many nodes to avoid collisions and maintain reliable transmission conditions. The design of MAC protocols for underwater sensor network will be effective data collection, aggregation and networking to the sites where the data can be displayed and interpreted [12].

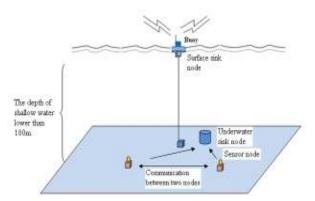


Figure 1. Network Model between Two Nodes in UWSN

The MAC protocol is very important in ensuring data reliability to the underwater sensor network. Different applications required different requirements on MAC protocol. In this project, the aim is to design a MAC protocol for long term applications such as water quality monitoring for agriculture purposes. This application is not sensitive to end-to-end delay because the communication link of UWSN is using RF electromagnetic waves that have high propagation speed which is 3×10^8 m/s. Hence, the propagation delay is very low and can be ignored. The most important goal of MAC protocol for such underwater sensor network is to solve the data packet collision efficiently in terms of energy consumption. Another goals of the designing MAC protocol in this project are to achieve guarantee high network throughput, low consumption and low channel access delay.

A reason why current terrestrial Radio Frequency (RF) based MAC protocol cannot be used directly in UWSN because of the harsh physical characteristics of underwater channel. Currently, the existing MAC protocol for UWSN is using acoustic as a link for communications. There has no existing MAC protocol that can be adapted in UWSN using RF electromagnetic link. This project will be developed a MAC protocol that can be adapt in UWSN for shallow water environment using RF electromagnetic link. A major difference between RF and acoustic propagation is the velocity of propagation. Radio waves travel at the speed of light as mentioned above. The speed of sound in water is around 1500 m/s, and it varies significantly with temperature, density and salinity, causing acoustic waves to travel on curved paths.

A. Related Works

Table 1 shows the existing MAC protocol in UWSN with the mechanism or algorithm, advantages and disadvantages for each protocol. All of this protocol tailored for underwater acoustic network. There has no MAC protocol that can be adapted for underwater RF network. The most important goal of the MAC design for underwater sensor network is to resolve data packet collision efficiently in term of energy consumption.

TABLE 1: THE EXISTING MAC PROTOCOL IN UWSN

MAC protocol	Mechanism/algorithms	Advantages	Disadvantages
Distributed Energy- Efficient MAC protocol [13]	Based on the assumption that nodes follow sleep periods and is aimed at efficiently organizing the sleep schedules.	The chances of collision are very low and also energy is saved due to low duty cycle. It does not require centralized	The protocol only works well for low and uniformly distributed traffic.
		clock synchronization of nodes.	Low duty cycle saves energy but reduces throughput.
Reservation based MAC (R-MAC) [14]	Each node operates in listen and sleep modes periodically for same length of periods.	Transmission of control and data packets is scheduled at both sender and receiver that avoids data packet collision and increases fairness. No centralized scheduling and synchronization required. Burst based acknowledgement technique is provided that increases throughput and efficiency.	This protocol works fine when all nodes are static and no new node joins the network There is no technique proposed when a new node joins or a node failure occurs or a node wants to change its transmission schedule. The protocol has higher overheads in the form of control packets that make it inefficient in terms of bandwidth and energy.
CDMA Based MAC [15]	Nodes randomly access the channel transmitting a short header called the Extended Header (EH).	Increases the spectrum efficiency (bandwidth is higher) and thus reduces the error rate. The dynamic code length control algorithm helps in controlling the data bandwidth according to channel environment.	It is not suitable for densely deployed sensor nodes. Data cannot be widely spread to achieve the full benefits of noise immunity and security.
OFDMA Based MAC [16]	This protocol exploits the multipath characteristics of a fading acoustic channel It converts the channel into parallel independent acoustic sub-channels that undergo flat fading.	This protocol is useful in shallow water deployments, which are the most challenging scenarios. Reduce the energy consumption.	The protocol not provided any collision avoidance method.

B. Proposed Protocol

This research will be developed a MAC protocol that can be adapt in UWSN for shallow water environment using RF electromagnetic link. The proposed protocol will take the advantage of the R-MAC protocol proposed in [14]. The method that will be used is periodic sleep and listen scheme for collision avoidance and energy efficiency. Periodic sleep and listen scheme will reduce the energy waste in idle state and overhearing. Moreover, collision will be reducing because there is no synchronization requirement by allowing each node randomly select its own listen/sleep schedule. Energy efficient also will be focused on the measuring of the average time spent transmitting receiving and idle state per successfully delivered packet. The R-MAC protocol work similarly with proposed protocol but it has long latency when packet transmission error occurs because R-MAC simply resumes the packet transmission in the next period. The new proposed protocol will reduces the control packet overhead to make it more efficient in terms of bandwidth and energy.

The communication of nodes in R-MAC is through reservation packet (REV), acknowledgement packet for REV (ACK-REV), DATA and acknowledgement packet for data DATA (ACK-DATA). But for proposed protocol, combining the functionality of SYNC packet with REV packet will provide both energy efficient operations because we have eliminated the need of sending two packets and decrease control packet overhead.

The listen period of proposed protocol consist of SYNC packet as shown in Figure 2. During the SYNC period, protocol sends the SYNC packets periodically and synchronizes the listen time. The SYNC packet is very short and includes the address of the sender and the time of the next sleep. In the sleep period, all nodes sleep (radio off) but the node with the reverse schedules wake up at their scheduled and forward data packet. ACK-REV packet will notify all its neighbors about the reserved time slot if receiver ready for data transmission. Lastly, receiver sends ACK-DATA to the sender at the end of the transmission.

VI. FUTURE WORK

This research is primarily aimed to provide reliability data delivery for underwater wireless sensor network (UWSN) using RF electromagnetic communication. The research focuses on MAC protocol.

In MAC layer, a reliable MAC protocol will be proposed. The primary goal of the MAC protocol design for underwater sensor network is to resolve data packet collision efficiently in term of energy consumption. This is due to sensor nodes in UWSN are usually powered by batteries. The proposed protocol will take the advantage of the R-MAC protocol proposed in [14] using RF electromagnetic as a communication link. The method that

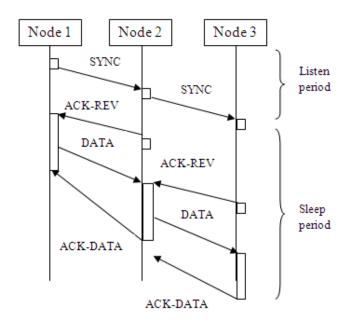


Figure 2. Proposed protocol

will be used is periodic sleep and listen scheme for collision avoidance and energy efficiency. Periodic sleep and listen scheme will reduce the energy waste in idle state and overhearing. Moreover, collision will be reducing because there is no synchronization requirement by allowing each node randomly selects its own listen/sleep schedule. Energy efficiency also will be focused on the measuring of the average time spent on transmitting, receiving and idle state per successfully delivered packet.

For future research, the transport protocol also should be developed to provide end-to-end reliability and congestion control for reliable data transmission.

VII. CONCLUSIONS

Data reliability of a sensor node is described as a probability of data packet being delivered from sensor node to the sink. Therefore, this MAC protocol design is needed to improve the reliability data delivery for efficient underwater communication and to enhance water monitoring and exploration applications. To achieve that, MAC protocol should provide collision avoidance and efficiency for managing and controlling communication channels which are shared by many nodes to avoid collisions and maintain reliable transmission conditions. On the other hand, transport protocol will be provided end-to-end reliability, congestion control and also energy efficiency

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