Underwater Wireless Sensor Networks: A Survey on Enabling Technologies, Localization Protocols, And Internet of Underwater Things

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Abstract- *Underwater communication remains a challenging technology via communication cables and the cost of underwater sensor network (UWSN) deployment is still very high. As an alternative, underwater wireless communication has been proposed and has received more attention in the last decade. Preliminary research indicated that the Radio Frequency (RF) and Magneto-Inductive (MI) communication achieve higher data rate in the near field communication. The optical communication achieves good performance when limited to the line-of-sight positioning. The acoustic communication allows long transmission range. However, it suffers from transmission losses and time-varying signal distortion due to its dependency on environmental properties. These latter are salinity, temperature, pressure, depth of transceivers, and the environment geometry. In this survey paper is focused on both the acoustic and magneto-inductive communications, which are the most used technologies for underwater networking. Such as acoustic communication is employed for applications requiring long communication range while the MI is used for real-time communication. Moreover, this paper highlights the trade-off between underwater properties, wireless communication technologies, and communication quality.*

Keywords- Underwater wireless sensor networks, underwater wireless communications, magneto-inductive communications, acoustic communications, information transfer, Internet of Underwater Things.

I. INTRODUCTION

Underwater communication remains realized until nowadays via communication cables due to the limited development of underwater wireless communications. However, the use of wires to ensure the connection between sensor nodes aster bottom results in costly sensor network deployment. For this more intention is given by the researcher community to the underwater wireless communication. Thus, it is known as a challenging communication medium when it's compared to terrestrial wired or wireless connections. Since allow transmission rate over a short distance is achieved via sophisticated transceivers. Moreover, the marine environment is characterized by several distinguishing features that make it unique and different from the atmosphere environment where the traditional terrestrial communication is performed. As described in the following sections, underwater communication faces several phenomena such as depth related impaction temperature, salinity, pressure, winds, and waves. Four technologies might be used as an underwater wireless channel. Radio Frequency (RF) employed for terrestrial wireless communication is also enabled for underwater communication; it achieves high data rate for short communication range and suffers from Doppler Effect. Optical transmissions also used for the marine environment where the blue-green wavelength is recommended for transmission that requires line-of-sight positioning. Another technology is the magnetic induction that is mostly used for internet of underwater things enabling real-time communication with significant bandwidth since its independent of the environmental impairments multipath fading and time-varying signal distortion. However, two issues restrict the use of this technology. Path loss caused by coupling and conductivity between coils. The near-field property due to the non-propagating property of the magnetic wave in the absence of the electric component. The latter technology is acoustic communication, which is the most popular in the underwater communications for its long communication range. Researchers working on the development of underwater sensor network should consider a design of a long-term goal that gives self-configuration ability for distributed sensor nodes within the network [1]. For this, Underwater Sensor Networks (UWSN) should be capable of configuring itself and managing node location to establish an efficient data communication environment. Unlike shallow water, vertical communication is usually required for a long-range indeed water to achieve data delivery toward the surface station. Acoustic and radio modems generally equip this latter. The acoustic communication is used to perform multiple parallel communications to gather data from sensor nodes. Where radio communication usually established with a satellite is employed to relay gathered data to the coastal sink. Differently from [1] where only the ocean bottom sensor nodes are considered and the Autonomous Underwater Vehicles (AUV) to relay data from the bottom to the surface. In [2], Sensor nodes are deployed in different depth to sense the given phenomenon. These sensor nodes use a floating buoy attached even to a surface station or the ocean bottom to keep itself floating at the specific depth. The floating buoy changes its depth, consequently the sensor node with it, by regulating the wire length that relays it to the sea surface or bottom. Although the floating buoys guarantee the easy and quick network deployment, it constitutes a vulnerable aspect of security due to its easy detection on the sea surface. In the first part, we focused on underwater acoustic communication due to its importance in the deployment of wide-range UWSNs. Firstly we give insight to the underwater acoustic signal propagation which severely depends on the environmental properties such as salinity, temperature, pressure, and depth of transceivers. Absorption and transmission losses formulas are given as well as Channel Impulse Response (CIR). Mobile nodes as Unmanned Underwater Vehicle (UUV) or Autonomous Underwater Vehicle (AUV)are required from wide-range UWSN to cover void region. Additionally, terrestrial GPS does not work well for sensor nodes anchored to the ocean bottom. For this, nodes localization becomes the most challenging issue in UWSN. This study pointed out the major issues facing the physical layer of Underwater Acoustic Sensor Network, which has a strong relationship with the MAC and routing layer. Afterward, we discuss MI wireless communication, which is an emerging communication method proposed as an alternative for various complicated applications. Such as the Internet of Underwater Things (IoUT) [3], [4], and Wireless Body Area Networks (WBANs) [5]. The preference of using MI communication for those applications is due to the limited interference created between transceivers. UWSN has been considered as a promising sensor network to support the development of IoUT [6]. It is composed of multiple under water objects interconnected between each other through MIor another communication medium. Used for monitoring the vast unexplored marine area and enables applications for smart cities development [7]. The acronym IoUT might also describe the Internet of Underground Things [8]. Such as sensor nodes and transceivers are deployed in the underground for monitoring and sensing the target soil area in real time. The paper is organized as follows: Section II gives insight into Acoustic Communications by providing a brief discussing of the acoustic propagation properties and the energy efficiency of UWSNs. As well as describing localization issues. Magneto-Inductive Communication is by describing the different MI channel path loss models while the paper is concluded in Section V.

Applications of Internet of Underwater things: Application for real-time monitoring of agricultural field has been risen based on IoUT.

i. The main object of this application is to enhance food production through monitoring physical soil parameters such as soil moisture, acidity (pH), Organic and others [8].
ii. IoUT connects heterogeneous underwater objects such as AUVs, anchored underwater sensors, and smart submarine.

II. ACOUSTIC COMMUNICATIONS

The Knowledge of Underwater Acoustic Sensor Networks

Since an underwater acoustic sensor network is used to collect data when events occur in the underwater environment, a reliable and effective route from source node to the destination node is necessary. Even though many routing protocols have been proposed for terrestrial wireless sensor networks, considering the differences between the underwater environment and the terrestrial environment, terrestrial routing protocols are different from UASN routing protocols. For better understanding the differences between underwater communication and terrestrial communication, and the difficulties in routing protocol design for underwater acoustic sensor networks, some investigation of the characteristics of underwater acoustic communication is necessary.

A. ACOUSTICS PROPAGATION:

1) Transmission loss: The underwater acoustic channel (UAC) is known as one of the most challenging communication media actually in use. The acoustic signal traveling between the transmitter and receiver incurs a lot of destructive mechanisms that attenuate received signals. We classified three significant losses types as follows, spreading loss, absorption loss, scattering loss.

2) 2)Multipath loss: In this, we considered that acoustic signal propagates over a single path, which is not the case in the real underwater environment. In underwater the acoustic signal propagates over a long distance is performed through multipath, this is due to the surface and bottom reflection. Although sound refraction resulting from the underwater spatial variability of sound speed, exist only in deep water.

B. DYNAMIC UNDERWATER ACOUSTIC PROPAGATION

1) TIME-VARYING DISTORTION The time variability of the UAC channel can be driven principally by two sources: temporal changeability in the propagation environment and motion of transceiver platforms.

Environmental conditions resulting in these changes give rise to different time scales signal fluctuations. Some changes occur on a long timescale that has no impact on the communication signals (e.g., seasonal changes in temperature).Others happen in a short timescale that affects the communication signals. The latter changes are induced by the internal waves, turbulent ship wakes, fish migration, eddies, other phenomena, and river out flows. As a result, reflection point displacement engenders signal scattering, and Doppler spread due to path length fluctuation.

2) UNDERWATER ACOUSTIC NOISE: Over the last three decade, oceans have known a continuous increase in human activities in particular shipping traffic that causes significant underwater pollution noise. This noise is crucial on the acoustic channel characterization for underwater communication. Several works have focused on publishing data set and spectral analysis to investigate the impact on the acoustic spectrum. The underwater acoustic noise can be distinguished into two categories: site-specific noise and ambient noise. The first category is the noise that depends on geographic localization as those resulting from the breaking ice and sea creatures. The second category includes noises such as turbulence, shipping, waves, and thermal.

Underwater acoustic noise sources are also distinguished by their impact on marine life. Such as two categories are recognized: natural and anthropogenic sources. For natural sources, marine animals already know about their existence in the environment and can easily be adapted to it. Among them, we found sources as waves, rain and seismic, which are characterized by high power and use the same frequency band as marine animals. This might create difficulties in the distance estimation and communication between these animals. The other category is known for its severe impact on the marine animals since it's human-generated, e.g. sonar systems, shipping, and explosions, etc. (Figure 1). Those noises are difficult to distinguish from the natural noises which create accidental collisions between animals and mass beaching. Moreover, animal's behavior is altered due to the latter noise kind, leading them to miss some important noises causing temporary or permanent hearing loss and tissue damage.

C. ENERGY EFFICIENCY: Sensors of UWSNs are mostly battery powered, which is characterized by its limited energy, knowing that battery replacement or recharging is not useful in the harsh and far area. For this, saving energy to increase the network lifetime is becoming the principal occupancy of UWSN systems.

D. LOCALIZATION IN UWSNS: Potential applications of UWSN require the use of Unmanned Underwater Vehicle (UUV) that gives the mobility aspect of the network to perform well the data gathering task. These vehicles are also known as underwater drone are divided into two categories: Remotely Operated Underwater Vehicles (ROVs) which are controlled from the surface sink or the ship using the remote human operator, and Autonomous Underwater Vehicles (AUVs) which operate autonomously Using a predefined set of rules and instructions to navigate in deep water without the need of direct human control. For simplicity, the latter category is called by the underwater mobile nodes which are equipped by acoustic modems for communication and sensors for data gathering. Therefore, mobile nodes need to be accurately localized in order to increase the data gathering accuracy and maintain the knowledge of the whole network topology. The Global Positioning System (GPS) proposed for WSNs does not work well fordeep underwater localization due to severe RF Impairments in this environment.

Table 1: Comparison of different underwater communication techniques.

Type	Data rates	Communication ranges	dependency
MI	$\sim Mb/s$	$10 - \tilde{}100\,m$	Conductivity
EM	$\sim Mb/s$	$\leq 10\,m$	Conductivity, multipath Acoustic
Optical	$\sim Mb/s$	$10 - \tilde{}100\,m$	Light scattering, line of sight communication, ambient light noise
Acoustic	$\sim kb/s$	$\sim km$	Multipath, Doppler, temperature, pressure, salinity, environmental sound noise

E. MAGNETO-INDUCTIVE COMMUNICATIONS

Magnetic Induction (MI) is mostly used for Underground Wireless Communication Networks (UGWN) [94] [43] where the air is no longer the propagation medium but rock, soil, and water. The feasibility and effectiveness of MI wireless communication technique for the marine environment are demonstrated in [47]. UGWN enable many sophisticated and critical application, including earthquake and landslide forecast, deep sea surveillance and mine wire fare [8], [48]. Communication over those mediums face significant challenges such as the path loss, dynamic channel condition, and large antenna size. Underwater sensor nodes equipped with wire or tuned coil creates a Magnetic field that is used to achieve the MI communication between each other.

A. MI CHANNEL

MI-based communication uses an alternating AC magnetic field as a channel. The difference between the MI signals and the useful electromagnetic (EM) signals in radio communications the neglected component of the electric field that leads to the non-propagating property of MI waves. In order to circulate the data on the MIcarrier modulation techniques as used in radio communication could be considered.

III. A DETAILED STUDY OF FEW UWSN IS GIVEN BELOW

A. “Shallow water acoustic networks," J. G. Proakis, E. M. Sozer, J. A. Rice, and M. Stojanovic[1]

In this paper, presented with basics principle & constraints in design of shallow water acoustic networks which help to use for variety of undersea sensor to on shore facilities. Major methods used by author is including that Severe power limitations imposed by battery power, severe bandwidth limitations & channel characteristics such as long propagation times, multipath, and signal fading. In last, multiple access methods, network protocol, routing algorithm also consider.

According to author for shallow water network employed in sea web embodies the power and bandwidth essential in digital communication through underwater acoustic channel.

B. Advances in underwater acoustic networking," in Mobile Ad Hoc Networking: Cutting Edge Directions T. Melodia, H. Kulhandjian, L.-C. Kuo, and E. Demirors[2]

In this Paper, author provided a comprehensive account of recent advances in underwater acoustic communications and networking. Described the typical communication architecture of an underwater network. Discussed key notions of underwater acoustic propagation and the state of the art in acoustic communication techniques at the physical layer. Author described the challenges posed by the peculiarities of the underwater channel with particular reference to monitoring applications for the ocean environment. This paper presented an overview of the recent advances in protocol design at the medium access control and network layers in addition to cross-layer design. The objective of this paper is to encourage research efforts to lay down fundamental basis for the development of new advanced communication techniques for efficient underwater communication and networking for enhanced ocean monitoring and exploration applications.

C. Survey on advances in magnetic induction-based wireless underground sensor networks," S. Kisseleff, I. F. Akyildiz, and W. H. Gerstacker[15]

In this paper summarize that, optimization techniques for the two most important cases of magnetic induction based WUSNs, MI waveguides and direct MI transmission based WUSNs. The main objective of this paper was to provide bounds for the throughput of such networks. For this purpose, author derived new channel, noise, and interference models, which differ from the existing models and incorporate all relevant signal reflections which occur in magnetic induction based communication systems. In sum up, that in some cases, especially if the average transmission distance between nodes is not too large, the MI waveguides based WUSNs do not provide a better performance, as expected from the motivation given by the previous works in this field. In other cases, a large throughput gain compared to the direct MI transmission based WUSNs is observed. However, this gain is reached at the price of a much higher deployment effort and less flexibility of the system.

D. Localization for large-scale underwater sensor networks," -Z. Zhou, J.-H. Cui, and S. Zhou[39]

In summary, the main contributions of this paper are as follows: (1) The first to propose a hybrid localization approach which, post facto, corrects data locations at a base station to improve the overall network communication cost and sensor power. With this hybrid localization approach, the period of sensor self-localization can be extended and thus decrease the computational overheads and high energy requirements of sensors; (2) Data Localization Correction Approach is easily implemented and is cost-efficient in both computing time and memory space, and (3)Author, analyze DLCA performance under different marine environments by simulating ocean-current speeds based on kinematic models and also compare the results to several range-based localization approaches.

E. Internet of underwater things: Challenges and routing protocols'.-C. Liou, C.-C. Kao, C.-H. Chang, Y.-S. Lin, and C.-J. Huang[6]

In this paper, the Internet of Underwater Things. This paper provides useful information about the IoUT: (1) applications; (2) challenges; and (3) channel models. Furthermore, when the transmission distance increases, the corresponding SNR decreases, and the BER increases, the delivery ratio decreases. The models are reasonable, and are expected to help researchers investigate the communication protocols on IoUT.

IV. CHALLENGES AND OPPORTUNITIES

While UWSN is a promising new field and may help in exploring the unfathomed world that lies underwater, there are many challenges and opportunities as well.

1. Unpredictable Underwater Environment. Underwater conditions are extremely unpredictable. The anonymous high water pressure, unpredictable underwater activities, and uneven depths of the underwater surface make it difficult to design and deploy UWSNs.
2. Intricate Network Design and Deployment. Due to the unpredictable underwater environment, it is extremely difficult to deploy the network underwater which works reliably and wirelessly. The current tethered technology allows constrained communication but it incurs significant cost of deployment, maintenance, and device recovery to cope with volatile undersea conditions.
3. Unscalability. Traditional underwater exploration relies on either a single high-cost underwater device or a small scale underwater network. Neither existing technology is suitable for applications covering a large area. Enabling a scalable underwater sensor network technology is essential for exploring a huge underwater space.
4. Unreliable Information. Underwater nodes are in continuous motion due to the water currents; thus locating nodes underwater becomes much more crucial. Traditional positioning and localization systems do not work underwater. Therefore, underwater conditions dismantle the location of the nodes and the network topology which ultimately makes the information transmission unreliable.

V. CONCLUSION

The survey investigates the existing algorithms developed in the past years by various methods research communities across the world.EM channel used in terrestrial wireless sensor networks is not suitable for the use in underwater communication due to path losses and dynamic channel conditions. Thus acoustic and MIare mostly used in UWSN. Since they allow good channel quality and reduce the impact of the harsh environmental conditions. Otherwise, some applications cannot use acoustic communication as a wireless channel since they require high throughput and real-time communication. So as MI is recommended for this case mainly for the internet of underwater things, which attract huge interest in these days. Since MI performs in near field and requires some enhancement to extend its transmission range. As a perspective, we plan to consider a heterogeneous channel based on the advantages of both acoustic and MI channels. This channel will enable a sophisticated geographic routing for multi-hop data transfer from the bottom to the sea surface station. In this protocol, acoustic communication is used between nodes for low data rate and long communication range.

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