Hindawi
Wireless Communications and Mobile Computing
Volume 2019, Article ID 6470359, 20 pages
https://doi.org/10.1155/2019/6470359

*Review Article*

# Underwater Wireless Sensor Networks: A Review of Recent Issues and Challenges

**Khalid Mahmood Awan,[1] Peer Azmat Shah ,[1] Khalid Iqbal,[2] Saira Gillani,[3] Waqas Ahmad,[1] and Yunyoung Nam [4]**

[1]*Internet Communication & Networks (ICNet) Research Lab, Department of Computer Science, COMSATS University Islamabad, Attock 43600, Pakistan*
[2]*Pattern Recognition, Images and Data Engineering (PRIDE) Lab, Department of Computer Science, COMSATS University Islamabad, Attock 43600, Pakistan*
[3]*College of computing and informatics Saudi Electronic University, Jeddah, Saudi Arabia*
[4]*Department of Computer Science and Engineering, Soonchunhyang University, Asan 31538, Republic of Korea*

Correspondence should be addressed to Yunyoung Nam; ynam.sch@gmail.com

Received 29 June 2018; Revised 1 October 2018; Accepted 11 November 2018; Published 1 January 2019

Guest Editor: Sungchang Lee



Underwater Wireless Sensor Networks (UWSNs) contain several components such as vehicles and sensors that are deployed in a specific acoustic area to perform collaborative monitoring and data collection tasks. These networks are used interactively between different nodes and ground-based stations. Presently, UWSNs face issues and challenges regarding limited bandwidth, high propagation delay, 3D topology, media access control, routing, resource utilization, and power constraints. In the last few decades, research community provided different methodologies to overcome these issues and challenges; however, some of them are still open for research due to variable characteristics of underwater environment. In this paper, a survey of UWSN regarding underwater communication channel, environmental factors, localization, media access control, routing protocols, and effect of packet size on communication is conducted. We compared presently available methodologies and discussed their pros and cons to highlight new directions of research for further improvement in underwater sensor networks.

## 1. Introduction

Technique of sending and receiving message under the utilization of sound propagation in underwater environment is known as acoustic communication. Underwater sensor networks have number of vehicles and sensors that deploy in a specific area to perform collaborative monitoring and data collection tasks [1]. Traditionally for the monitoring of ocean bottom, oceanographic sensors are deployed for recording data at a fix location and recover the instruments at the completion of task. The major disadvantage of traditional approach is lack of interactive communication between different ends, recorded data can never get during any mission, and in case of any failure recorded data will be destroyed.

Underwater Sensor Networks support a wide variety of applications [2]; for example, aquatic surveillance, river and sea pollution discovery, monitoring, oceanographic data compilation, and commercial exploit the aquatic environment [3]. Underwater Sensor Networks can be utilized in any scenario from underwater warfare to the monitoring of environmental conditions [2]. Underwater Sensor Networks face constraints like limited bandwidth, high propagation delay, 3D topology, and power constraints. Radio and optical waves are not feasible for communication at each point of ocean. Under the entire limitations underwater sensor networks can only utilize acoustic signal that is a technique which is utilized by nature from the birth of ocean [4, 5]. Speed of sound is considered constant in underwater environment. However, speed of sound is affected by temperature, depth, and salinity of underwater environment. These factors produce variations in speed of sound in underwater environment [6]. Underwater acoustic channel frequencies spectrum, especially on mid-frequencies, is heavily shared

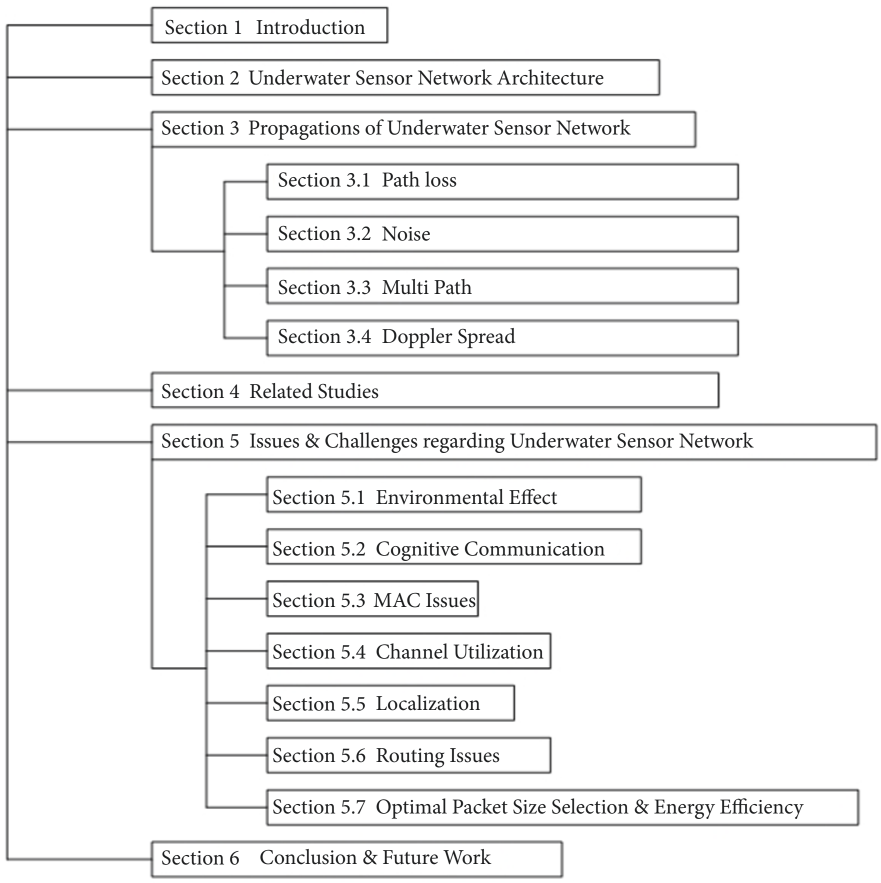



Figure 1: Overview of research work.

by various acoustic users in underwater environment. Still acoustic spectrum is temporally and spatially underutilized in underwater environment [7]. Variable characteristics of underwater environment have become a challenge for utilizing acoustic channel. For example, multipath propagation results in fading and phase fluctuations; Doppler Effect is observed due to the movement of both the sender and receiver nods. Speed of sound and underwater noise are other factors that influences the performance of acoustic channel [8].

Underwater sensor networks nodes are not static like ground-based sensor networks nodes. Instead, they move due to different activities and circumstances of underwater environment, usually 2-3m/sec with water currents. Sensed data is meaningful only when localization is involved. Another major issue that is affecting underwater sensor networks is energy saving. Because of nodes mobility, the majority of offered energy competent protocols become inappropriate for underwater sensor networks. Different protocols regarding land-based sensor networks are, for example, Directed Diffusion, Gradient, Rumor routing, TTDD, and SPIN. However, because of mobility and rapid change in network topology these existing grounds based routing protocols cannot perform efficiently in underwater environment [9]. Optimal packet size is depending on protocol characteristic like offered load and bit error rate. Poor packet size selection decreases the performance of the network throughput efficiency, latency, and resource utilization and energy consumption in multihop underwater networks can be greatly improved by a using optimum packet size [10–13].

To improve the better utilization of the available resources in underwater environment considering the energy and life time of network is discussed in detail in this paper. Balancing of energy consumption is carried out in underwater environment using the proposed techniques. The important contributions of this work are not only to highlight the deep and shallow ocean characteristics, but also to present the effect of temperature in acoustic communication and effect of temperature in noise, errors and protocols due to variation in environmental factors. In addition, classification of routing protocols for UWSNs and their comparison in terms of bounded latency, multipath, load balancing, energy consumption, geographic information, communication overhead, and time complexity. Similarly, data delivery ratios for single and multipath and the strengths and weaknesses of MAC protocols, with the used topology, are compared [14–16].

The paper is organized as illustrated in Figure 1. Section 2 presents the architecture of Underwater Wireless Sensor Networks. Section 3 describes propagation phenomena of

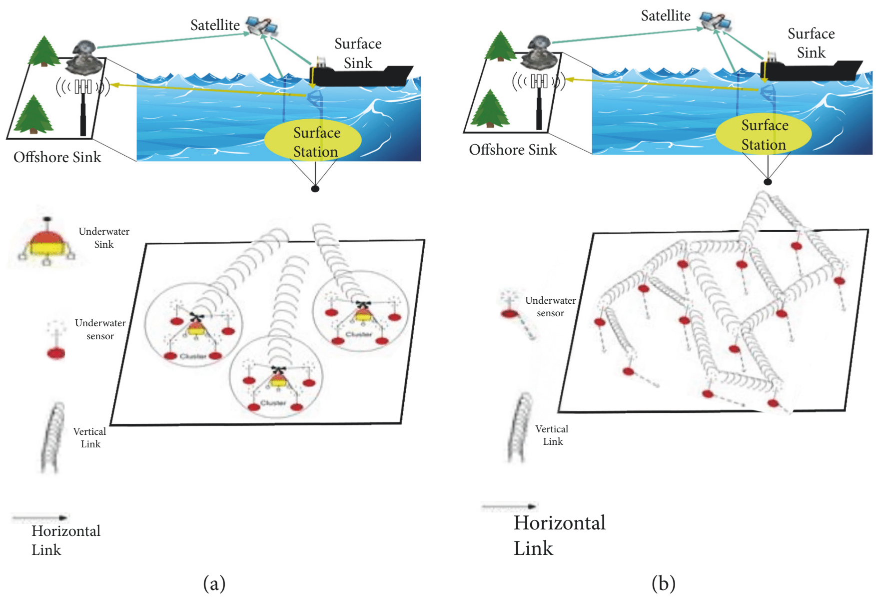



Figure 2: Two- and 3-dimensional networks architecture for UWSN regarding communication given in (a) and (b), respectively.

Underwater Wireless Sensor Networks. Section 4 presents previous achievements of different researcher in the form of related studies. The issues and challenges regarding underwater sensor networks are described in Section 5. Conclusion and future work are made in Section 6.

## 2. Underwater Sensor Networks Architecture

Underwater network's physical layer utilizes acoustic technology for communication. Limited bandwidth, capacity, and variable delays are characteristics of acoustic technology. Therefore, new data communication techniques and efficient protocols are required, for underwater acoustic networks. Designing the network topology requires significant devotion from designer, because underwater network performance is generally depending upon topology design. Network reliability should increase with efficient network topology and network reliability should also decrease with less efficient topology. Energy consumption of efficient network topology is highly less as compared to incorrect and less efficient topology design of underwater network. Design of topology for underwater sensor network is an open area for research [18, 19]. Underwater sensor networks architecture is shown in Figure 2.

*2.1. Underwater Sensor Networks in Two-Dimensions.* Deep ocean anchors are utilized for collection of sensor nodes in two-dimensional underwater sensor network architecture. Anchored underwater nodes use acoustic links to communicate with each other or underwater sinks. Underwater sinks are responsible to collect data from deep ocean sensors and provide it to offshore command stations, using surface stations. For this purpose, underwater sinks are provided in the company of horizontal and vertical acoustic transceivers. Purpose of horizontal transceivers is to communicate with sensor node, to collect data or provide them commands, as have been received by offshore command station, although vertical transceiver is used to send data to command station. Because ocean can be as deep as 10 km, vertical transceiver should contain enough range. Surface sink that is equipped with acoustic transceivers has the capability to manage parallel communication, by means of multiple organized underwater sinks. Surface sink is also equipped through extensive range radio frequency transmitters, to communicate with offshore sinks [18–21].

*2.2. Underwater Sensor Networks in Three Dimensions.* Activity required to present three-dimensional environments new architecture which is known as underwater three-dimensional networks is used. Sensor nodes float at different depth to monitor a specific activity in three-dimensional underwater networks. Traditional solution regarding underwater three-dimensional sensor networks is the use of surface buoys that provide ease in deploying such kind of network. But this solution is vulnerable to weather and tampering. Also, effortlessly can be discovered and disabled by enemies in the scenario of military operation. In underwater three-dimensional sensor networks architecture, ocean bottom is utilized to anchored sensor nodes. Depth of these nodes is controlled using wires which are attached with these anchors. Major challenge regarding such network is influenced by the current properties of the oceans [18–20].

## 3. Propagation Phenomena of Underwater Sensor Networks

Acoustic communication regarding underwater environment is a complex phenomenon because a lot of environmental factors affect acoustic communication. These factors are variable like long propagation delays, environmental noise,

Table 1: Deep and shallow ocean characteristics.

| Characteristics | Shallow Ocean | Deep Ocean |
|---|---|---|
| **Depth** | 0 m to 100 m | 100 m to 10000 m |
| **Temperature** | High | Low |
| **Multi-path Loss** | Surface Reflection | Both Surface and Bottom Reflection |
| **Spreading Factor (K)** | Cylindrical | Spherical |

path loss, Doppler spread, and multipath effect. Underwater environmental factors make acoustic channel highly variable. They also create bandwidth dependency upon both frequency and distance between two nodes. Generally, ocean is divided into two parts; these are shallow and deep ocean. Shallow and deep ocean characteristics are described in the Table 1. Shallow ocean highly affects acoustic channel because of high temperature gradient, multipath effect, surface noise, and large propagation delays, as compared to deep ocean. Underwater environment major propagation factors that affect acoustic communication are described in subsequent sections.

*3.1. Path Loss.* When sound propagates from underwater environment then some of its strength converts into heat. Sound wave propagation energy loss can be categorized into three main categories which are described below.

*(1) Geometric Spreading Loss*. When source generates acoustic signal it propagates away from the source in the form of wave fronts. It is independent of frequency, however, depending upon distance covered by wave front. Geometric spreading is divided into two types: first spherical spreading that depicts deep ocean communication; second cylindrical spreading that depicts shallow water communication [5, 18].

*(2) Attenuation*. Attenuation is defined as "wave energy converted into some other form of energy", such as heat energy, absorbed by the medium used. Within acoustic communication, this phenomenon is compassionated as acoustic energy is converted into heat. The converted heat is absorbed by underwater environment. Attenuation is directly proportional to frequency and distance [5, 18].

*(3) Scattering Loss*. Deviation regarding the line of sight of a signal or change in angle is generally a physical property. Underwater channel also contains this property that effects acoustic channel data transmission during communication. Surface roughness increases due to increase in the wind speed. That raises the end product of scattering surface. Scattering surface not only affects delays but also affects power loss [5, 18].

*3.2. Noise.* Noise can be defined as a quality of communication system that degrades signal strength of any communication system. In case of underwater acoustic channel there exist different kinds of noises. Underwater noises can be divided into two major categories. These are ambient noise and noises by human beings. Both kinds of noises are described in detail in the following sections.

*(1) Noise by Human Beings*. These noises are due to heavy machinery utilization, shipping activities, fishing activities, military activities, sonar activities, and aircraft activities and because of heavy data traffic sending and receiving activities cause different kind of disturbance and interference during acoustic communication. Sometime noises due to human beings also disturb natural acoustic communication [18].

*(2) Ambient Noise*. Ambient noise is a complex phenomenon regarding underwater communication. It can also be defined as a combination of different sources that cannot uniquely identify [22]. Ambient noise is also called background noise that occurs as a result of unidentified sources [5]. These noises are divided into four major categories which are known as wind, shipping, thermal, and the turbulence [1]. Wind noise is due to breakage of wave or because of bubbles created by air. Noise can be simply predicted and forecast from weather forecasts because of dependence of noise upon wind speed. Large number of ships present at large distance from communication system in ocean produce high traffic noise in acoustic communication, if sound propagation is good enough. Ships consider main source of anthropogenic ambient noise [22]. Turbulence can be defined as surface disturbance due to waves or tides that generates low frequencies that results continuous noise in acoustic communication. Underlying noise is considered as thermal noise in the absence of all other sources of noise, including self-noise. Thermal noise is directly proportional to the frequency which is used for acoustic communication [23].

*3.3. Multipath.* Sound propagation in shallow water is influenced by surface reflections while deep water propagation is affected by bottom reflection that becomes cause of large and variable communication delay in acoustic communication. A major cause that makes acoustic signal weak is called multipath effect that becomes cause of intersymbol interference which also makes acoustic data transmission difficult and erroneous. Vertical acoustic channel is less affected by multipath effect as compared to horizontal acoustic channel [18, 19, 21].

To address the problem of long propagation delay and high lite error rate a routing protocol QERP was proposed to handle end-to-end delay but this protocol still needs to address the mobility issues [14]. Mostly in deep oceans because of variable sound speed, refraction of sound occurs that cases of multipath effect in acoustic channel. Number

Table 2: Effect of temperature on acoustic communication.

| **S.No** | Area Focused | Findings | **Sound speed Effects due to temperature** |
|---|---|---|---|
| 01 | Underwater Wireless Sensor Networks: Routing Issues and Future Challenges | Speed of sound increases due to increase in the temperature of ocean and decreases in colder oceans. Approximately, the mount of 1°c can boost the speed of sound near to 4.0 m/s. | Increase with temperature |
| 02 | Prospects and Problems of Wireless Communication for Underwater Sensor Networks | Shallow water effects acoustic communication by temperature gradients, ambient noises regarding surface and multi-path effect because of reflection and refraction. | Effects communication |
| 03 | Survey of temperature variation effect on underwater acoustic wireless transmission | Speed of sound is affected by temperature, depth and salinity of underwater environment. These factors produce variations in speed of sound in underwater environment. | Variation in speed |
| 04 | Variability of available capacity because of depth and temperature in the underwater acoustic communication channel | Determine acoustic channel capacity on short distances, increasing temperature and depth as a result gets higher channel capacity and throughput rates. | Improves throughput |
| 05 | Underwater Channel Simulation | Temperature of sea surface is much higher as is compared to the bottom temperature. Velocity of sound is also affected with increase in depth, salinity and temperature. | Increases with temperature |
| 06 | Mathematical equation for sound speed in the oceans | Temperature is a dominating factor that has effect on the sound speed. | Increases with temperature |

of propagation paths, propagation delays, and its strength are determined by acoustic channel impulse response that is influenced by channel reflection and geometry. Large numbers of paths exist in acoustic channel but only those paths are considered which have less energy loss and reflections. All other paths are discarded as a result only finite number of paths remains for acoustic communication and data transfer [24].

*3.4. Doppler Spread.* Because of channel flaws, wireless signals practice a diversity of degradations. For example, electromagnetic signal affects by interference, reflections, and attenuation; acoustic signals regarding underwater are also affected by same kind of factors [25]. Underwater acoustic channel is complex channel due to time variation and space variation. The relative motion of transmitter and receiver that causes the mean frequency shift is called Doppler shift. Although the fluctuation of frequency in the region of this Doppler shift is called Doppler spread [8], two types of influences are observed on acoustic channel because of Doppler Effect: first is pulse width that will be compressed or stretched and second is frequency offset as a result of frequency offset compressing or expending of signal time domain occurring [26].

## 4. Related Studies

Presently underwater communication system utilizes electromagnetic, optics, and acoustic data transmission techniques to send data among different positions. Electromagnetic communication technique is affected by conducting nature of seawater while optic waves are applicable on very short distance because optic waves are absorbed by seawater. Acoustic communication is only one technique that has better performance regarding underwater communication due to less attenuation in seawater. Acoustic communication also has less attenuation in deep and thermally stable oceans. Shallow water affects acoustic communication by temperature gradients, ambient noises regarding surface, and multipath effect because of reflection and refraction [5]. Speed of sound is not constant in underwater environment instead of this speed of sound varies from point to point. Close to the surface of ocean speed of sound is found to be 1500 m/s that is four times higher than speed of sound in air but very slow as compared to speed of optics that is $3 \times 10^8$ m/s and electromagnetic in air. Table 2 shows the effects of temperature on acoustic communication and its effects with variation in temperature.

Natural acoustic systems and artificial acoustic systems both use acoustic channel in case of underwater environment. Both acoustic systems heavily utilize middle frequencies; because of that their communication affects each other, as they use same frequencies. Still, acoustic channel spectrum is not utilized efficiently. High spectrum utilization and to develop an environment friendly underwater acoustic network (UAN), Luo et al. [7] present Cognitive Acoustic (CA) as a promising technique. This technique has the capability to wisely sense whether any part of the spectrum is engaged by any other and also has the capability to change their frequency, power, or even other operation parameters to temporarily use the idle frequencies without interfering with other networks. The CA technique makes communication environment friendly and erroneous free by avoiding interference with marine mammals. An important issue in underwater environment is use of low frequencies which results in low data rate. Other problems like energy dispersion and reflection also degrade the performance of devices. In this study the author proposed a model for underwater communication which monitors the performance of the wireless sensor nodes based on different frequencies and achieved high data rate [27].

Acoustic channel is highly variant because of unique challenges, e.g., narrow bandwidth, long propagation delays, variable speed of sound, reflection, refraction, and large propagation losses. These unique challenges also create problems regarding media access control protocols. Media Access Control protocols have two main categories these are scheduled protocols and contention-based protocols. Scheduled protocols avoid collision among transmission nodes, while in contention-based protocols nodes compete each other for sharing a single channel. Scheduled based protocols, for example, Time Division Multiple Access (TDMA), are not efficient due to large propagation delays; frequency division multiple access (FDMA) is not suitable due to the narrow bandwidth; and Code Division Multiple Access (CDMA) is suitable for underwater acoustic networks. While contention-based protocols are not appropriate for underwater communications [9], Lv et al. [28] propose TDMA based Underwater Acoustic Channel Access Control method (UA-MAC), to improve channel utilization in dense Mobile Underwater Wireless Sensor Networks (MUWSN). Aim is to solve the difficulties like, time schedule to access the channel, hidden terminal problem, and end-to-end delay. Underwater acoustic channel access method puts into practice the piggyback scheme and as a result fewer packets are exchanged. Using that kind of methodology, collision decreases and saves a lot of energy. Shahab-u-deen et al. [29] combine different media access control protocols in a suite called Adaptive Multimode Medium Access Control for Underwater Acoustic Networks, because no single protocol can complete the requirements of underwater sensor network media access control. Adaptive Multimode Medium Access Control for Underwater Acoustic Networks aims to improve the performance regarding traffic intensity. This suite switches from one protocol to the other based on network requirements, traffic intensity, and quality-of-service requirements.

Channel capacity is affected by temperature, depth, propagation loss, and ambient noise of underwater environment where sensor nodes are deployed. Path loss is the function of distance (between pair of nodes) and frequency utilized for communication. These factors affect acoustic channel capacity. However, bandwidth increases with increase in depth and temperature and decreases with increase in distance. Sehgal et al. [30] determine acoustic channel capacity on short distances, increasing temperature and depth as a result gets higher channel capacity and throughput rates. Large bit error rates and large delays are characteristics of acoustic channel. Harris et al. [31] compare three different techniques adaptation of packet size, forward error correction, and adaptation of packet train size to overcome long delays and large bit error rates and also to improve channel utilization. Packet train length overcomes long propagation delays in addition of time wastage while packet size adaptation and forward error correction overcome both large propagation delays and bit error rates. Acoustic channel utilization also increases under the utilization of packet size adaptation and forward error correction. Harris's analysis provides guidelines for creation of media access control and routing protocols.

Information regarding sensor nodes is useful only when localization is involved in it. Large numbers of terrestrial localization schemes are available but because of unique challenges (sensor nodes movement with ocean currents, high cost of senor nodes, global position system inapplicability, and limited battery power) of underwater sensor networks they cannot be utilized directly. Guo et al. [32] provide a mechanism of localization which is known as Anchor-Free Localization Algorithm (AFLA). This algorithm has ability of self-localization for anchor-free sensor nodes. AFLA uses anchor nodes and cables to restrict sensor node in underwater environment. AFLA's goal is to create an efficient localization scheme for underwater sensor networks. Simulation results prove that AFLA is an efficient localization scheme and it can be utilizable in both static and dynamic networks scenarios. Table 3 highlights the major effects of noise and bit error rate during acoustic communication using different protocols.

Major issues, e.g., energy conservation and mobility regarding underwater sensor networks, create unique challenges for designing of routing protocols and make all existing ground-based routing protocols (proactive and reactive) inadequate. Underwater environment required such protocols that are efficient in energy consumption, manage random variation in topology, and consider asymmetric links and huge propagation delay. DU et al. [33] present a protocol which is known as Level-Based Adaptive Geo-Routing (LB-AGR) that divides communication traffic into four categories. These are upstream to sink, downstream to sensor nodes, downstream to specific nodes, and downstream to all nodes. Data forwarding is based upon density, available battery power, and level between neighbors that is used to elect next best hop. Level-Based Adaptive Geo-Routing goal is to achieve minimum communication delay, consume less battery power, and improve delivery ratio as well as received packets percentage. This protocol reduces communication end-to-end delays and improves delivery ratio and efficient utilization of battery power. Efficient utilization of battery power is the major concern of underwater sensor networks routing protocols.

Huang et al. [34] proposed a routing protocol that utilized energy efficiently using fuzzy logic and decision tree techniques for data forwarding towards the surface sink. Routing protocol goal is to utilize battery power efficiently in that manner that reduces the expenditures of energy during acoustic communication. Protocol reduces traffic overload on acoustic channel and reduces energy consumption also. Presently, for routing protocols minimum end-to-end delay and high efficiency are the major requirements for underwater sensor networks. Ali et al. [35] present an end-to-end delay

Table 3: Effect of noise, errors, and protocols.

| S. No. | Area of research | Findings | Noise effect | Bit error rate | Protocol usage |
|---|---|---|---|---|---|
| 01 | Challenges: Building Scalable and Distributed Underwater Wireless Sensor Networks (UWSNs) for Aquatic Applications, | Time Division Multiple Access (TDMA) is not efficient due to large propagation delays, Frequency Division Multiple Access (FDMA) is not suitable due to the narrow bandwidth and Code Division Multiple Access (CDMA) is suitable for underwater acoustic networks. While contention-based protocols are not appropriate for underwater communications. | N/A | N/A | (TDMA) is not efficient; (FDMA) is not suitable. (CDMA) is suitable |
| 02 | Prospects and Problems of Wireless Communication for Underwater Sensor Networks | Acoustic communication also has less attenuation in deep and thermally stable oceans. Shallow water effects acoustic communication by temperature gradients, ambient noises regarding surface and multi-path effect because of reflection and refraction. | Decreases by ambient noises | less attenuation in deep and thermally stable oceans | N/A |
| 03 | Analyzing the Performance of Channel in Underwater Wireless Sensor Networks (UWSN) | Multi-path propagation results in fading and phase fluctuations, Doppler Effect is observed due to the movement of both the sender and receiver nods. Speed of sound and underwater noise are other factors that influences the performance of acoustic channel. | Decreases by ambient noises | Fading and phase fluctuations, Doppler Effect | N/A |
| 04 | Optimized packet size selection in underwater wireless sensor network communications | Effect of bit error rate, interference, collision, retransmission leading selection of optimal packet size is also considered and achieves improvement in all metric e.g., throughput, energy consumption, resource utilization and packet latency underutilization of optimal packet size selection. | N/A | Less bit errors in small packets | N/A |
| 05 | Choosing the packet size in multi-hop underwater networks | Data packets are large enough as compared to the control packets and because of control and data packet collision entire data packet is discarded that causes of huge number of retransmissions and energy dissipation. | N/A | Error due to control and data packet collision entire data packet discarded | CDMA, DACAP |
| 06 | Challenges for efficient communication in underwater acoustic sensor networks | A major cause that makes acoustic signal weak is called multi-path effect, that becomes cause of inter-symbol interference also makes acoustic data transmission difficult and erroneous. Vertical acoustic channel is less affected by multi-path effect as compared to horizontal acoustic channel. | N/A | Interference and multi-path effect | N/A |
| 07 | Ocean ambient noise: Its measurement and its significance to marine animals | Large number of ships present at large distance from communication system in ocean produce high traffic noise in acoustic communication, if sound propagation is good enough. Ships consider main source of anthropogenic ambient noise. | N/A | Decreases due to ships noise | N/A |
| 08 | SEA 6 Technical report: Underwater ambient noise | Turbulence can be defined as surface disturbance due to waves or tides that generates low frequencies that results continuous noise in acoustic communication. Underlying noise is considered as thermal noise in the absence of all other sources of noise, including self-noise. Thermal noise is directly proportional to the frequency which is used for acoustic communication. | surface disturbance of waves or tides generates low frequencies that results in noise in acoustic communication | Errors due to noise | N/A |
| 09 | Doppler estimation and correction for shallow underwater acoustic communications | Because of channel flaws, Wireless signals practice a diversity of degradations. For example, electromagnetic signal affects by interference, reflections, and attenuation, acoustic signals regarding underwater are also affected by same kind of factors. | N/A | High BER due to interference, reflections, and attenuation | N/A |

Table 3: Continued.

| S. No. | Area of research | Findings | Noise effect | Bit error rate | Protocol usage |
|---|---|---|---|---|---|
| 10 | Study on Doppler effects estimate in underwater acoustic communication | Two types of influences are observed on acoustic channel because of Doppler Effect, first is pulse width that will be compressed or stretched and second is frequency offset as a result of frequency offset compressing or expending of signal time domain occurs. | N/A | Doppler Effect, frequency offset | N/A |

efficient routing protocol which is known as Diagonal and Vertical Routing Protocol for Underwater Sensor Network (DVRP). Packet forwarding mechanism is depending upon angle of flooding zone and flooding nodes are also controlled by manipulating the angle for flood region to avoid the flooding over the entire network. Diagonal and Vertical Routing Protocol goal is to minimize end-to-end delay and consume less battery power of sensor nodes. Diagonal and Vertical Routing Protocol has no need to maintain large routing tables; instead of this it uses its local information to rout data packet towards destination. Adding or removing new nodes create no disturbance for existing nodes.

Basagni et al. [12] select two protocols. These are Code Division Multiple Access (CDMA) and Distance Aware Collision Avoidance Protocol (DACAP) and compare them by varying packet size, bit error rate, and traffic load. Under the exploitation of variant packet sizes, bit error rates, and traffic load, author determines the impact of packet size upon multihop underwater sensor networks. Basagni et al. conducted an experiment using different fixed (predetermine) packet sizes and packet size is not change according to environmental factors. Data packets are large enough as compared to the control packets and because of control and data packet collision entire data packet is discarded that causes of huge number of retransmissions and energy dissipation.

Basagni et al. [11] introduce technique of data fragmentation that minimizes disadvantage of collision by partitioned long data packet into small fragments. Technique is experimented upon DACAP by considering and nonconsidering data fragmentations. Fragmentation decreases retransmissions, energy consumption, and packet latency as well as overall traffic and huge overhead. Basagni et al. do not consider the factor of varying bandwidth and interference and as a result of fragmentation traffic load increases that congested communication channel. Since improving the throughput of a single hop packet size is considering a critical parameter regarding communication in field of underwater sensor networks. Underwater sensor networks use the half duplex methodology for communication that can be avoided by utilizing optimal packet size selection. In this proposed feeding control system sensor nodes works in groups for necessary decision making. The contribution of this system is to avoid loss of food and then reduces negative impact on environment as well as economically feasible [27, 36].

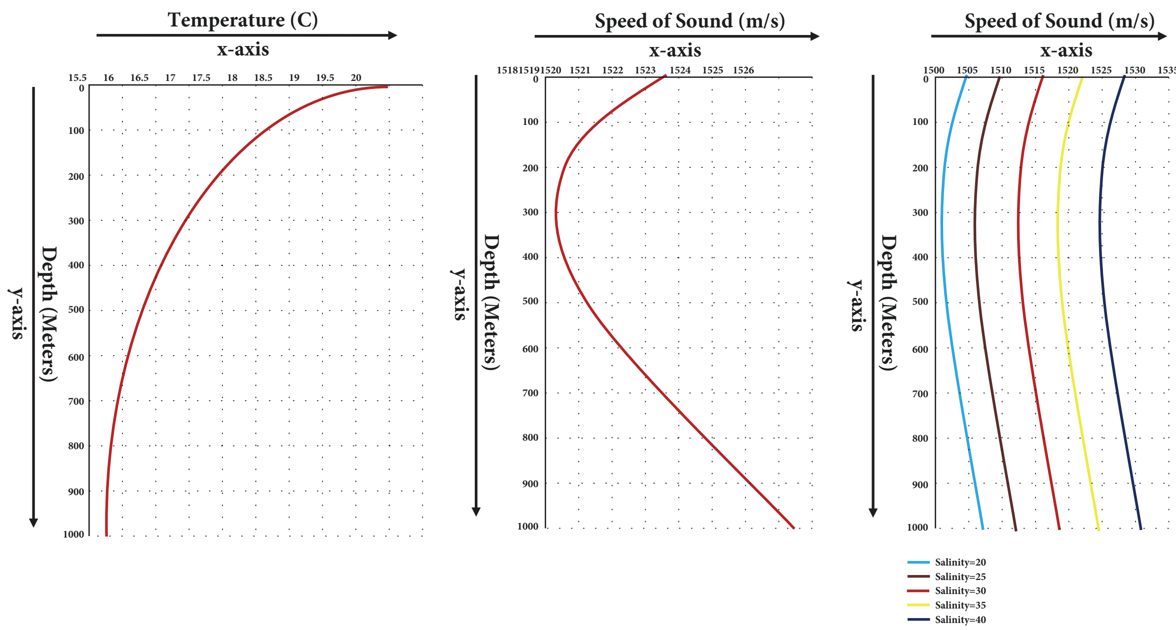
QERP is proposed by Faheem et al. [15] to improve the reliability of data transfer in underwater acoustic sensor networks. The mechanism used for organizing sensor nodes is in the form of small clusters which are connected hierarchically for distributed energy and data transfer evenly. This technique reduces the probability of packet loss and preserves high link quality in underwater environment. The issue with this technique is no mobility and node density is not addressed [37].

Basagni et al. [10] observe the performance of multihop network in provisions of throughput, energy efficiency, and latency. Effect of bit error rate, interference, collision, and retransmission leading selection of optimal packet size is also considered. For this, Basagni et al. select two-media access control protocol CDMA and DACAP and compare their results and change the network deployment scenario and then observe the effect of the packet size upon throughput, energy efficiency, and latency of network. Basagni et al. achieve improvement in all metric, e.g., throughput, energy consumption, resource utilization, and packet latency underutilization of optimal packet size selection. Junget al. [38] have investigated energy efficiency using optimal packet size under the utilization of NS-2 simulator. Authors create a cluster of 100 nodes in dimensions of 2 km×2 km×200 m. Experiment proves a relationship between energy efficiency and packet size. Optimal packet size reduces utilization of extra energy. Erroneous channel offers large bit error rate that causes wastage of large energy amount, but the utilization of optimal packet size for erroneous channel reduces wastage of energy. Reliability (in sense of data delivery) is a major issue regarding underwater sensor networks because of highly variant environment.

Ayaz et al. [13] provide an algorithm that has the ability to determine the best suitable packet size for reliable data transfer, using two-hop acknowledgment methodology for same packet size. Algorithm investigates optimal data packet size for underwater sensor networks, with energy efficiency as the optimization metric. The goal of the algorithm is reliable data delivery from source node to destination node or surface sink is a major requirement of a network. In this section, paper presents a brief overview of different advancements in the field of Underwater Wireless Sensor Networks that uses acoustic channel for communication. But still some issues and challenges exist. That not only affects the performance of above described methodologies but also needs solution from research community. These issues, challenges, and drawbacks are discussed in the next section.

## 5. Issues and Challenges regarding Underwater Sensor Networks

In this section, issues and challenges regarding underwater sensor networks are described which makes underwater communication hard and problematic as compared to




(a) Temperature versus depth (b) Depth versus sound velocity (c) Salinity versus sound velocity

Figure 3: Variation of environmental factors (depth, temperature, and salinity).

terrestrial sensor network communication. In underwater sensor network issues and challenges like reliability and efficient utilization of acoustic communication link, optimal packet size selection for communication, power consumption, distributed localization, environmental effects, media access control, and network routing protocol still need to address. These problems require attention from academia and research community. Following section describes efforts which are made by researchers to address these issues.

*5.1. Environmental Effect.* Marine organisms are affected due to anthropogenic sound which is emitted in underwater environment, in various ways; e.g., organs of hearing are affected in shape of hearing loss; high potential sound waves which are received by marines can injure and also can become the cause of their death [52]. Presently, underwater communication utilizes different kind of communication methodologies, e.g., optic, electromagnetic, and acoustic. Only acoustic communication meets the requirements of underwater communication due to less attenuation and low absorption in sea water [5].

Speed of sound is not constant in ocean. Near to the surface of the ocean the speed of sound is 1500 m/s that is four times, as compared to the sound speed in air. Upper part of ocean is called surface layer, in which change of temperature is less significant while in layer beneath (thermocline) temperature is prominent factor which affects the speed of the sound as compared to others [53].

Speed of sound increases due to increase in the temperature of ocean and decreases in colder oceans. Approximately, the mount of $1^{\circ}$c can boost the speed of sound near to 4.0 m/s. The boost of 1 practical salinity unit can enhance the speed of sound nearly 1.4 m/s; when we walk off deep, the pressure of ocean water continues to enhance; as a result each 1 km depth will boost the sound speed of nearly 17 m/s [4]. In this survey authors discussed issues in underwater environment and observed that acoustic waves are used to get different environment parameters and there is no standardization of parameters for the monitoring of underwater environment, which results in the variety of monitoring system but none of them is a standard [54].

Temperature of sea surface is much higher as is compared to the bottom temperature. As is shown Figure 3, temperature is falling with depth and then becomes constant. Velocity of sound is also affected with increase in depth, salinity, and temperature, because these are the major factors that affect speed of sound in underwater environment. The effect of these environmental parameters can be observed in three domains. In first domain the impact of temperature is dominating, as compared to the other parameters, but in second domain both depth and temperature are dominating factors upon the sound speed. In third domain, the sound speed is purely dominated by the depth. Speed of sound is also depending upon salinity. Speed of the sound increases with the increasing salinity of the sea water, but the shape of the curve does not change [55, 56].

Underwater communication networks must utilize such kind of sound waves which do not affect natural acoustic communication and the organs of the water creature. In the development of underwater communication technique utmost care must be taken regarding the life of marine animals (organ) and their communication. It is still an open area for research and it needs solution from research community.

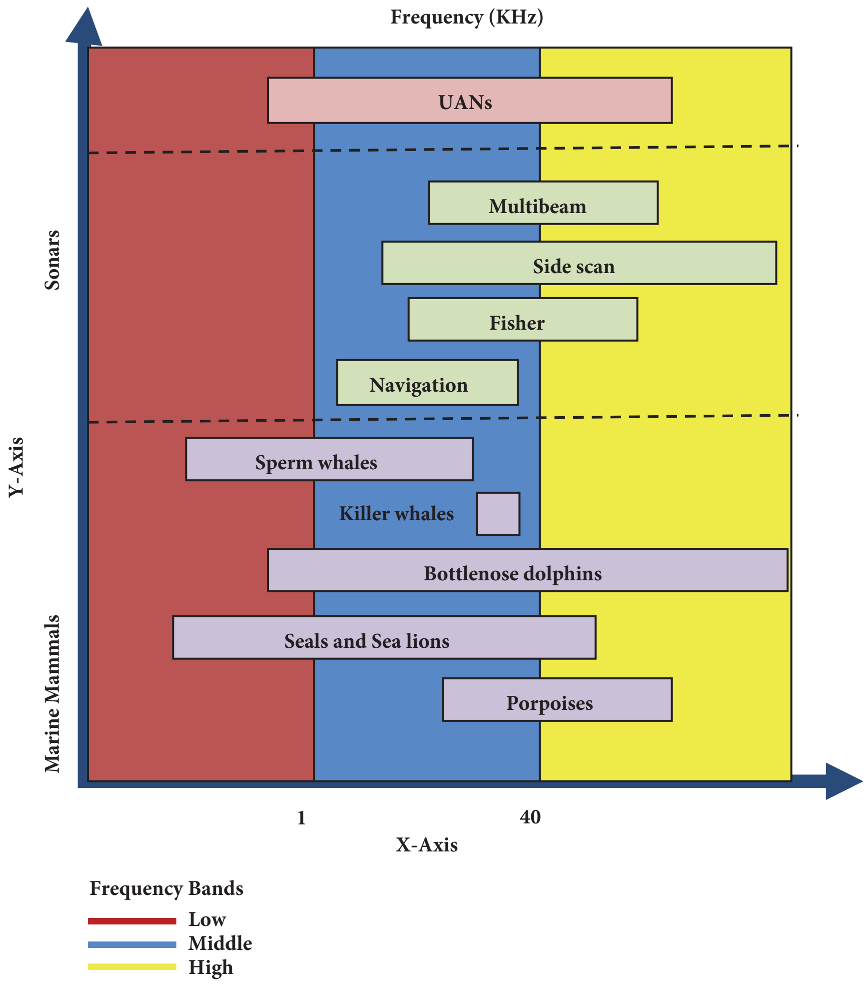



Figure 4: The acoustic spectrum usage in underwater environment.

*5.2. Cognitive Communication.* Because of attenuation, the available communication frequencies are mostly limited, usually from tens of hertz to hundreds of kilohertz in underwater environment. Mostly artificial acoustic systems and natural acoustic systems utilize the frequency band from 1 kHz to 100 kHz that makes the acoustic channel crowded. Frequency utilized by artificial acoustic systems is overlapping with natural acoustic systems, for example, marine mammals.

The underwater acoustic system overlapped spectrum usage is summarized in Figure 4. That indicating the fact about the underwater spectrum, especially on mid-frequencies, is heavily shared by various acoustic users. Still, acoustic spectrum is temporally and spatially underutilized in underwater environments.

Unfortunately, existing underwater acoustic networks designs have mainly focused on the single network scenario, and very few have considered the presence of nearby acoustic activities. Furthermore, the mobility and idle listening of acoustic systems may cause the spectrum to be underutilized temporally. The directional transmission and reception of acoustic systems may potentially cause the spectrum to be underutilized spatially. For high spectrum utilization and to develop an environment friendly with underwater acoustic networks, CA is presented as a promising technique. This technique can intelligently detect whether any part of the spectrum is engaged by any other. Also, it can change its frequency, power, or even its other operational parameters to temporarily use the idle frequencies without interfering into other networks.

The CA technique makes communication environment friendly by avoiding interference with marine mammals. Hence, each user first senses the surrounding spectrum before sending and receiving in underwater acoustic networks. Sending and receiving only take place when the sensing frequencies are idle. Thus, CA users can prevent using frequencies, which are engaged by marine mammals and look for new idle frequencies for communications. When marine organisms discharge the spectrum, CA users reuse these idle frequencies again. There exist some recently developed protocols which support dynamic spectrum management while underwater CA network (UCAN) is still underexplored area. Presently, CA technique is suffering from different features of underwater environment, e.g., long propagation delay, narrowband, long preamble embedded by acoustic modems, severe busy terminal problem of acoustic modems, and highly dynamic underwater channel. The unique characteristics of underwater channel provide challenges for the design of CA network. These challenges are spectrum sensing, dynamic power control, spectrum sensing strategy, spectrum sharing, and spectrum decision [7].

Efficient utilization of acoustic spectrum is a major requirement of the time because partial utilization makes acoustic communication very congested upon central frequencies that is mostly utilized by natural acoustic systems. Future developments regarding acoustic channel which will be aware of acoustic spectrum will make better utilization of unutilized parts of acoustic spectrum.

*5.3. MAC Issues.* Acoustic channel affects from various problems, for example, narrow bandwidth and huge transmission delays. Furthermore, acoustic channel has exclusive challenges regarding media access control. Media Access Control protocols have two main categories. First is called scheduled protocol that has avoided collision between transmission nodes. Second is known as contention-based protocols where nodes compete each other for sharing a single channel.

Working of different protocols varies with respect to environment. FDMA is not appropriate because of the constricted bandwidth of acoustic channel for underwater, whereas TDMA is not efficient, due to large propagation delays of acoustic channel. Several antenna elements are deployed at convinced access points, then Spatial Division Multiple Access (SDMA) is also an applicable option [9]. Underwater sensor networks are characterized as containing long propagation delay and low data rate. TDMA based underwater acoustic channel access method (UA-MAC) is proposed to improve channel utilization in dense Mobile Underwater Wireless Sensor Networks (MUWSN). According to the analysis of Lv et al. and depending upon the challenges of media access control protocol in MUWSN, underwater acoustic channel access method aims to solve the difficulties like, time schedule to access the channel, hidden terminal problem, and end-to-end delay. Moreover, underwater acoustic channel access method which is implementing piggyback method and fewer packets are exchanged, because of this reason, collision decreases, and a lot of energy is also saved. Reliable data delivery is the major concern for data gathering, navigation, and observation of the ocean regarding the field of underwater sensor networks [28].

*5.4. Channel Utilization.* Designing a highly utilizable channel is a great challenge, due to the characteristics of underwater environment, for example, multipath propagation which results in fading and phase fluctuations. Doppler Effect is another problem which is observed due to the movement of both the sender and receiver nods. Speed of sound and underwater noise are, further, factors which influence the performance of acoustic channel [8].

Sehgal et al. [30] analyzed the channel capacity which depends upon depth and temperature by considering propagation loss and ambient noise. Sehgal et al. compare attenuation modes as Thorp's model with Fisher and Simmons model. Thorp model considers fixed values of depth and temperature and not considering any change regarding depth and temperature, for the calculation of acoustic channel capacity. However, on the other side Fisher and Simmons model considers change regarding depth and temperature. Results show that channel capacity and utilization of acoustic channel increases with high throughput because of increase in both temperature and depth in case of short distances. Sehgal et al. also describe that nodes in deep ocean get high bandwidth and higher throughput rates. Higher channel capacity utilizes the same power with increasing depth. Bandwidth and channel capacity depend upon temperature and depth. Networks those have small area to cover get benefit from this model. Although for the networks which cover long distances no solution is provided in this sense. Same power is consumed for higher bandwidth capacity.

Due to bandwidth dependency upon the transmission distance, we get huge throughput if messages are forwarding using multihops instead of transmitting straight forwardly using one long single hop. During the analysis of [57], regarding acoustic channel physical model, under the consideration of propagation and ambient loss, Stojanovic determines bandwidth dependency upon distance. Underwater acoustic channels have the characteristic of path loss that depends not only upon the space among the nodes, but also upon frequency of the signal. Signal frequency can be utilized to measure the absorption loss of the communication signal, which occurs because of conversion of acoustic power into warm-up. Short communication link provides more bandwidth as compared to a longer one in an underwater acoustic system. Hence, utilizing this technique we get significant increase in information throughput and acoustic channel utilization efficiently. Simultaneously, less energy will be consumed; however, that phenomenon is also true regarding the radio channel.

Analysis of Harris et al. [31] depicts that use of three methods, adaptation of packet size, forward error correction, and adaptation of packet train size, belongs to improvement regarding acoustic channel utilization for underwater environment. MAC and routing protocols must consider energy consumption as well as end-to-end delays. Simulation's results have proved that utilization of these techniques raises increase in channel utilization in the presence of underwater acoustic channel constraints. First technique overcomes long delays of acoustic channel; however, for this effectiveness, network must compensate in the shape of time. Time exceeds prior to the sender can be reported of a failure. Alternatively, forward error correction and adaptation of packet size are inducting to overcome both the propagation delay and high bit error rates. Finally, we conclude these three kinds of methodologies; optimal selection of parameters depends upon the distance among the source and destination nodes, which affects both the propagation delay and the bandwidth for the underwater acoustic links utilizable channel is a great challenge, due to the multipath propagation, Doppler Effect, underwater noise, and dependence of channel capacity upon distance. In the presence of all these issues and challenges regarding underwater environment, acoustic communication

Table 4: Performance evaluation of LB-AGR with existing protocols of UWSNs.

| Factors | LB-AGR | VBF | VBVA |
|---|---|---|---|
| Energy Consumption | Low | High | High |
| Successful packet received | High | Low | Low |
| End-to-End interruption | Low | High | High |
| Delivery percentage | High | Low | Low |

demands methodologies from research community that better utilize the acoustic channel [58, 59].

*5.5. Localization.* In underwater acoustic networks, localization of sensor nods is not required because they are fixed by utilizing anchors or tied with surfaces buoys in the assistance of Global Positioning System (GPS). Although on the other side for underwater sensor networks, major problem is localization, mostly sensor nods are movable by means of the current of the ocean. Shaping accurately portable sensors nodes, locations in oceanic situations are more demanding as compared to underwater acoustic networks [9]. However, localization is the major issue in underwater sensor network scenario, because GPS signals (electromagnetic) do not efficiently propagate through sea water. Only acoustic communication is feasible in underwater environment. Localization techniques for underwater sensor networks can be categorized as range based and range free techniques, static reference nodes and dynamic reference nodes, and single stage and multistage schemes. All techniques perform well in simulations but they are not experimented in same conditions or assumptions [60]. This review article discussed the state-of-the-art localization based and localization free routing protocol. The major problem in routing is limited bandwidth, energy consumption, propagation delay, and short of memory [61].

Existing schemes consider a predefined locations map, using anchored nodes, for controlling the locations of sensor nodes. In deep water scenarios, special kind of nodes which get commands from control stations, for example, AUVs or surfaces buoys, is used. All these mechanisms are very costly, and their performance is not much efficient. Alternatively, in terrestrial sensor wireless networks every node maintains its location later than deployment. In contrary, sensor nodes in underwater scenarios do not maintain their location after deployment. Instead of this they shift by means of ocean current, tide, and other aspects. To regulate the shun nodes from deviation, from the place of deployment, generally, attach them to predetermined anchors through cables.

Thus, the movement of underwater nodes is actively restricted. That motivates researches and they provide an idea of Anchor-Free Localization Algorithm that is called AFLA. AFLA is considered for sensor networks which are actively restricted in underwater environment. Anchor node's information does not require by AFLA, and constructs employ of the association of neighboring nodes. In both static and dynamic network scenarios AFLA can be utilized. This algorithm contains a self-localization mechanism for underwater anchor-free sensor nodes. It can localize all nodes without anchor node's assisting [32]. Although, this algorithm has efficient results in underwater scenario but the localization of a freely moving node is still an open area for research. Data is only meaningful when exact location information is attached with it.

*5.6. Routing Issues.* A major issue that is affecting underwater sensor networks is energy saving. Nodes mobility is another challenge in underwater sensor networks. Different protocols regarding land-based sensor networks are, for example, Directed Diffusion, Gradient, Rumor routing, TTDD, and SPIN. These protocols (Directed Diffusion, Gradient, Rumor routing, TTDD, and SPIN) are generally planned for at a standstill network. However, due to the mobility and very rapid change in "network topology" make, these existing ground-based routing protocols are insufficient for underwater environment [9].

Offered routing protocols for earthly sensor networks are separated into two extensive groups, Proactive and Reactive. Except, both have problems in underwater environment. Table Driven or Proactive protocols construct huge signaling overhead to set up the routs, more than ever for the first and each time when the topology is customized. Topologies are modified always, by the reason of continuous nodes movement, and due to the large acoustic signaling delays proactive protocols are not efficient solution for underwater environment. Because of huge acoustic delays and asymmetrical links, consequently, the protocols of these (Reactive scheme) natures are not appropriate for the underwater networks [4, 62]. Researchers make efforts to design such protocols which can perform better in underwater environment.

DU et al. [33] showed that Level-Based Adaptive Geo-Routing (LB-AGR) protocol traffic is divided into four categories. These categories are upstream to the sink, downstream to sensor nodes in elected area, downstream to specific node not considering of where the node is locating, and downstream to all the sensor nodes. Upstream of packets towards sink is forwarded in unicast manner to the best next hop, instead of broadcasting to every neighbor node as compared to present underwater sensor network routing protocols (VBF and VBVA). Level-Based Adaptive Geo-Routing considers the following factors for forwarding which are available energy, density, location, and level-difference between neighbor nodes which are used to determine the best next hop between multiple qualified candidates. Performance evaluations of Level-Based Adaptive Geo-Routing with existing protocols of underwater sensor networks are given in the Table 4.

Table 5: Comparison of packet fragmentation versus nonfragmentation.

| Factors | Fragmentation | Non-Fragmentation |
|---|---|---|
| Delay | Low | High |
| Energy Consumption | Low | High |
| Traffic load | High | Low |
| Channel utilization | Low | High |
| Collision effect | Low | High |

Forward tree trimming methodology is implemented, to avoid overload increase by forwarded packets and also to efficiently shrink the voltage expenditure of the sensor nodes [34]. A protocol that provides higher level of efficiency in the environment that is highly volatile, for example, underwater environment, is a major requirement of the time. An end-to-end delay efficient routing protocol which is known as Diagonal and Vertical Routing Protocol (DVRP) for underwater sensor network is presented. Data packet forwarding is depending upon the angle of flooding zone via the sender node, in the direction of the surface sink, in case of DVRP. Alternatively, the quantity of nodes that floods the packets of data is prohibited by manipulating the angle for flood region to avoid the flooding over the entire network. For increasing the life time of the network, DVRP is consciously preserving sensor nodes energy. In this (DVRP) network sensor nodes make local judgment of forwarding data packets underneath the restriction of energy status and flooding angle among them. Protocol does not keep the multifaceted routing tables and not depend on information regarding location. It is easy to include a fresh node, at any instance and any position in the network [35].

Routing is a primary concern for any category of network, and routing protocols are utilized for maintaining and discovering the paths. Underwater sensors network contains the issue regarding underwater network physical and network layer [62]. However, routing techniques regarding network layer are a new research area.

*5.7. Optimal Packet Size Selection and Energy Efficiency.* Basagni et al. [12] explore the packet size impact upon two protocols and measure end-to-end delay; throughput efficiency and energy per bit are utilized. Optimal packet size is depending upon protocol characteristic, just like offered load and bit error rate. Poor packet size selection decreases the performance of the network. Recently, the emphasis has shifted towards the multihop network, because it covers large area as compared to single hop networks. Optimal packet size selection is considered to increase the efficiency of that kind of networks. Stojanovic (upon point-to-point scenario at data link layer) has explored packet length optimization for maximizing throughput efficiency. Results have proved that packet size affects the performance of network.

Metrics such as throughput efficiency, latency, and energy consumption in multihop underwater networks can be greatly improved by a wisely choosing packet size. Basagni et al. use variable but predefined fixed size of the packets and determines the performance of CDMA and DACAP. Basagni et al., not changing the packet size point-to-point, means that, according to environmental factors and channel capacity at different parts of the ocean, using this kind of technique, performance and channel utilization will also increase. Basagni et al. [11] showed that size of control packets is very small as compared to the data packets. Once a data and control packet collision occur, the entire data packet must be discarded. Long data packet can be partitioned into smaller fragments, to minimize disadvantages of such kind of collisions. Effect of collision is reduced and remains to only few fragments by utilizing fragmentations; in that manner small numbers of chunks need to be retransmitted. Fragmentation reduces the overall traffic, as well as higher overhead and the number of retransmissions as well. This technique is applied upon DACAP. Advantages are achieved by fragmenting long packets, except because of fragmentation overhead increases in the network. For this reason, there exist an optimal number of fragments considering throughput efficiency. As traffic load increases, collisions also become higher.

Collision reduces because of fragmentation; another advantage of fragmentation is that overall energy consumption also reduces. Conversely, higher overhead is introduced for a single data transmission. Throughput efficiency decreases due to high traffic and higher bit error rate. However, the energy waste is considerably less as compared to no fragmentation. Packet fragmentation also reduces packet latency as shown in Table 5. Because of choosing optimum number of fragments higher throughput efficiency, lower energy consumption, and shorter packet latency are achieved.

Underwater sensor networks stop and wait mechanism, which is utilized in half duplex mode, can be avoided by using optimized packet size selection. Optimized packet size selection has positive impact upon multiple hope communication.

Basagni et al. [10] observe the performance of multihop network in terms of throughput, energy efficiency, and latency. They also considered the effect of bit error rate, interference, collision, and retransmission upon selecting the optimal packet size. Authors in [10] selected two-media access control protocol CDMA and DACAP and compares their results. In addition, variation in network deployment scenarios is observed to check the effect of the packet size upon throughput, energy efficiency, and latency of network. However, three fixed bandwidths are considered in all simulations despite the fact of point-to-point change in underwater bandwidth. The use of variable bandwidths is just like the use of variable data payloads by Basagni et al. [10], for better performance.

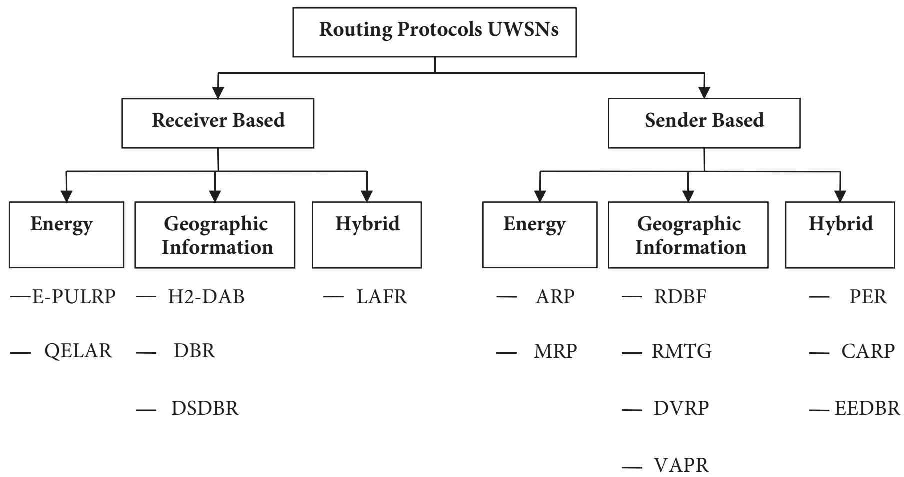



Figure 5: Classification of the routing protocols for UWSN.

Jung et al. [38] describe issues of energy efficiency and optimal packet size selection for efficient communication in underwater sensor networks. Challenges in underwater sensor networks are fading, multipath propagation delay, limited bandwidth, and energy constraints. Packet loss rate is higher because of acoustic channel refraction, reflection, and ambient noise. Ayaz et al. [13] have investigated optimal data packet size for underwater sensor networks, with energy efficiency as the optimization metric. Major challenges in Underwater Wireless Sensor Networks are high channel impairments, due to which higher error rates and temporary path losses occur in underwater sensor network. Congestion increases upon the nodes near the sinks, as data packets are forwarded towards the surface control station. Packet loss is caused by congestion which requires retransmissions that causes the loss of a significant amount of energy and leads to large end-to-end delays.

Packet size selection according to variations of environmental factors also improves acoustic communication and needs attention from research community. The communication techniques, which consider variations of underwater environment regarding acoustic channel, will produce better effect as compared to those which never consider these effects highly utilizable acoustic channel which is a great challenge, due to the multipath propagation, underwater noise, dependence of channel capacity upon distance, and Doppler Effect. Due to the movement of sensor nodes under the influence of ocean currents, meaningful information collection is also an issue that is called localization issue. Localization issue and frequent change in topology produce unique challenges for routing protocols. Packet size selection is a critical parameter regarding underwater sensor networks that can enhance energy consumption, channel utilization, and throughput of underwater sensor network. Hence these are the unique issues and challenges that need attention from research community. Routing protocols for UWSNS are classified in Figure 5.

Table 6 [63] shows that the efficiency in transmitting the packets is measured by publication year, bounded latency, multipath, load balancing, and energy consumption. In E-PULRP [39] and MRP [46] duty cycles are adopted for efficient energy consumption, while in QELAR [40] and LAFR [44] routes having minimum energy cost are selected by sensor nodes for purpose of energy transmission. Efficient energy consumption is the main objective for designing the UWSN protocols. Few of protocols discussed in Table 6 consider the load balancing technique to prolong the network life time. For data centric networks in UWSNs sensed data must be accurately transferred in bounded latency to the sink due to higher propagation delays in acoustic signals. Transmission delays are carefully analyzed in ARP [45] in which various priorities are assigned for packet transmission.

Multipath routing like DBR [42], MRP [46], and EEDBR [43] performs far better compared to single path routing protocols like QELAR [64] and H2-DAB [65].

Investigation of MAC protocol is shown in Table 7. Different MAC protocols which compared some of them are contention-based protocols like T-Lohi., R-MAC, MACUWASN, and MAFAMA and other or hybrid of contention based and contention-free like H-MAC, UWAN-MAC, and P-MAC.

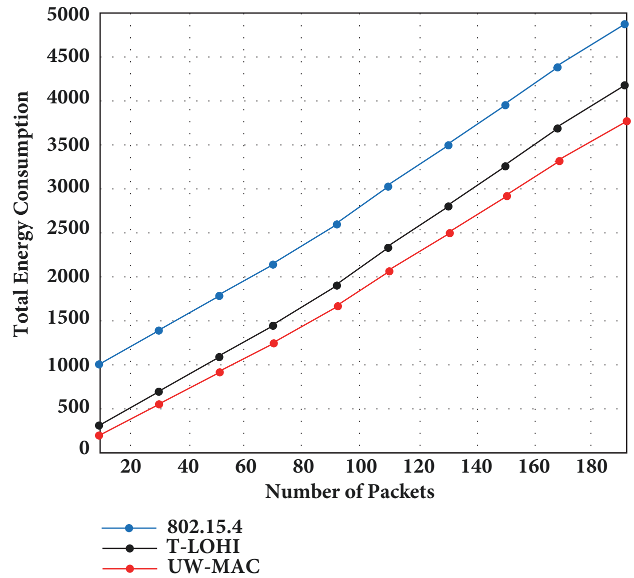
In Figure 6(a), it is shown that DBR are only depth-based routing protocol and while calculated costs considering different routing metrics are ERP2R and EEF. Common metrics for the all mentioned protocols is depth. Overhearing is used in ERP2R to make transmission decision during holding time beside this in EEF Overhearing is avoided due to which the efficiency of EEF is uplifted.

Total energy consumption is shown in Figure 6(a) for three contention avoidance MAC protocols, CSMA-CA, MACU WSN, and T-LOHI, for different packets numbers. Similar increasing energy consumption trend has been seen in each protocol. MACU WSN has less control packets as compared to CSMA-CA and T-LOHI.

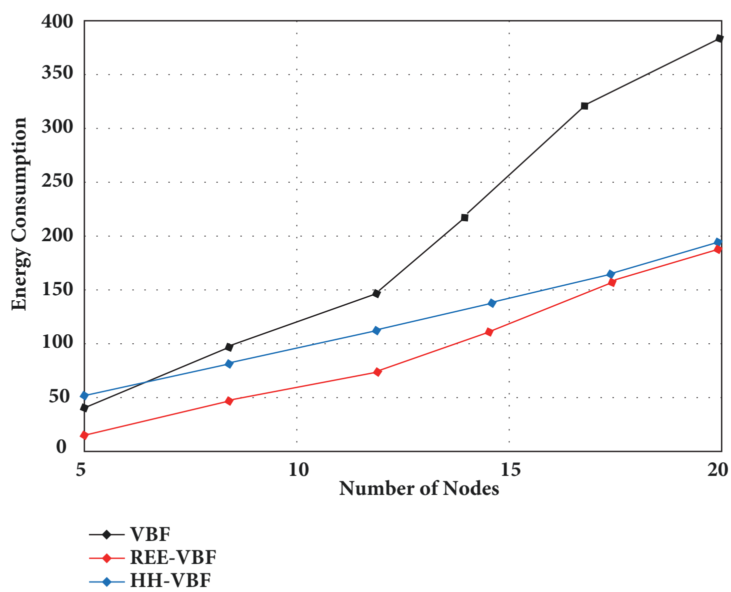
In Figure 6(b) comparison of VBF, REE-VBF, and HH-VBF has been shown. Vector based routing scheme is followed by these routing protocols; per hop vector is seen in HH- VBF that decreases the number of nodes involved in

Table 6: Comparison of the underwater routing protocols.

| Routing Protocol | Publication Year | Bounded latency | Multi-path | Load balancing | Based | | Energy Consumption | Geographic information | | Communication overhead | Time complexity |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Receiver | Sender | | Location | Depth | | |
| E-PULRP[39] | 2010 | × | × | × | √ | × | Medium | × | × | Low | O(n) |
| QELAR [40] | 2011 | × | × | × | √ | × | Low | × | × | Low | O(m1) |
| H2-DAB [41] | 2009 | × | × | × | √ | × | Low | × | √ | Low | O(n2) |
| DBR [42] | 2008 | × | √ | × | √ | × | High | × | √ | Low | O(m1) |
| DSDBR [43] | 2014 | √ | √ | × | √ | × | Medium | × | √ | Low | O(m1) |
| LAFR [44] | 2013 | × | √ | × | √ | × | High | × | × | Low | O(n×m1) |
| ARP [45] | 2008 | √ | √ | × | × | √ | High | √ | × | High | O(m1) |
| MRP [46] | 2013 | × | √ | × | × | √ | Low | × | × | Low | O(m2) |
| RDBF [47] | 2014 | × | √ | √ | × | √ | High | √ | × | High | O(n×m1) |
| RMTG [48] | 2011 | × | √ | × | × | √ | High | √ | × | High | O(n2) |
| DVRP [35] | 2014 | × | × | × | × | √ | High | √ | × | Median | O(m1) |
| VAPR [49] | 2013 | × | √ | × | × | √ | High | × | √ | Median | O(m1) |
| PER [34] | 2011 | × | √ | × | × | √ | Medium | × | × | High | O(n2) |
| CARP [50] | 2015 | × | × | × | × | √ | High | × | × | High | O(m1) |
| EEDBR [51] | 2012 | × | √ | × | × | √ | Medium | × | × | High | O(m1) |




(a)




(b)

Figure 6: (a) Energy consumption of T-Lohi and MACUWASN [17]. (b) Energy consumption of VBF, REE-VBF, and HH-VBF [17].

routing to make it more energy efficient than VBF. On the other hand, instead of flooding, optimal relay is selected in REE-VBF due to which the performances of REE-VBF and HH-VBF have passed the similar points.

In Figure 7, different constraints are shown which are considered while designing the routing protocols for underwater sensor networks (UWSNs); these constraints may vary according to situation and requirement for a scenario.

## 6. Conclusion and Future Directions

In this paper, we have discussed several techniques of underwater sensor networks. The objective of the reviewed techniques is to overcome the underwater challenges and to give directions to future researchers. Also, we presented a vibrant view to academia by providing a base for a better solution. In this perspective, we have presented future directions which are still not yet explored in this research area. A better communication technique can be proposed by considering environmental effect during communication. In the development of underwater communication technique utmost care must be taken regarding the life of marine animals and their communication. The deep digging out in the areas regarding nonlinear sound propagation of acoustic signals can be more useful for designing future communication techniques. The future identified research areas include cognitive networks area and underwater spectrum for their efficient use. Major challenges for the design of cognitive acoustic network

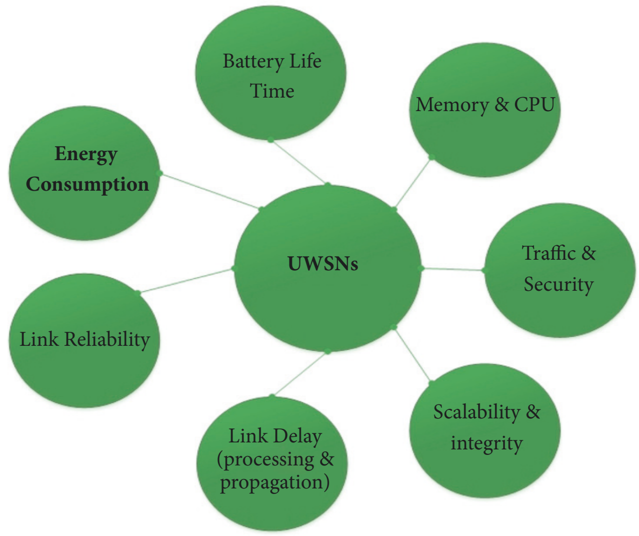



Figure 7: UWSNs constraints for designing routing protocols.

Table 7: Comparison MCA protocols.

| Protocol | Based | Topology | Advantages | Disadvantages |
|---|---|---|---|---|
| T-Lohi | Contention | Not fixed/Distributed | It is used to solve the space time & uncertain data reservation problem while using short wake up time to reduce energy consumption. | Node is required to be idle and listen to the channel each in contention round. |
| R-MAC | Contention | Multi-hop | TC & data packets are scheduled to the both sender and receiver side. | There is No technique to join for new nodes when node dies or left. |
| H-MAC | Hybrid | Centralized | It accepts the benefits from both contentions based &contention-free protocols while low power consumption/energy reservation. | Not Optimal for dense & heavily loaded network. |
| UWAN-MAC | Hybrid | Dense network | It achieves synchronized locally schedule even when long propagation delay is present because it required small duty cycle. | Difficult to achieve high throughput due to small duty cycle feature. |
| P-MAC | Hybrid | Centralized | According to information of VDL it works dynamically & adaptively. | The addition of P-MAC with multichannel& ad-hoc mechanisms. |
| MFAMA | Contention | Mobile UWASN | A greedy approach intends to maximize throughput. | pay compensation to the Fairness. |

are spectrum sensing, dynamic power control, spectrum sensing strategy, spectrum sharing, and spectrum decision. Therefore, routing and media access control protocols need to design by taking care of maximizing channel utilization. Standardization is highly required at media access control level. In addition, standards for underwater sensor networks are another challenge for academia. Further investigation is required in localization for underwater sensor networks. A GPS like localization sachem is still not created for underwater sensor networks and localization of a freely moving node is still an open area for research. Besides this, variable length packet in communication can further be investigated. Thus, we intend to target in future the variable packet size selection to improve the utilization of acoustic channel.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

## Acknowledgments

This research was funded by the Soonchunhyang University Research Fund and the MSIP (Ministry of Science, ICT and

Future Planning), Korea, grant number IITP-2018-2014-1-00720 and the APC was funded by IITP-2018-2014-1-00720.

## References

[1] N.-S. N. Ismail, L. A. Hussein, and S. H. S. Ariffin, "Analyzing the performance of acoustic channel in underwater wireless sensor network(UWSN)," in *Proceedings of the Asia Modelling Symposium 2010: 4th International Conference on Mathematical Modelling and Computer Simulation, AMS2010*, pp. 550–555, Malaysia, May 2010.

[2] T. Cinar and M. Bulent Orencik, "An underwater acoustic channel model using ray tracing in ns-2," in *Proceedings of the 2009 2nd IFIP Wireless Days (WD 2009)*, pp. 1–6, Paris, December 2009.

[3] J. Lloret, "Underwater sensor nodes and networks," *Sensors*, vol. 13, no. 9, pp. 11782–11796, 2013.

[4] M. Ayaz and A. Abdullah, "Underwater wireless sensor networks: Routing issues and future challenges," in *Proceedings of 7th International Conference on Advances in Mobile Computing and Multimedia, MoMM2009*, pp. 370–375, Malaysia, December 2009.

[5] L. Liu, S. Zhou, and J. H. Cui, "Prospects and problems of wireless communication for underwater sensor networks," *Wireless Communications and Mobile Computing*, vol. 8, no. 8, pp. 977–994, 2008.

[6] G. Zaibi, N. Nasri, A. Kacouri, and M. Samet, "Survey of temperature variation effect on underwater acoustic wireless transmission," *ICGST-CNIR Journal*, vol. 9, 2009.

[7] Y. Luo, L. Pu, M. Zuba, Z. Peng, and J.-H. Cui, "Challenges and opportunities of underwater cognitive acoustic networks," *IEEE Transactions on Emerging Topics in Computing*, vol. 2, no. 2, pp. 198–211, 2014.

[8] X.-P. Gu, Y. Yang, and R.-L. Hu, "Analyzing the performance of channel in Underwater Wireless Sensor Networks(UWSN)," in *Proceedings of the 2011 International Conference on Advanced in Control Engineering and Information Science, CEIS 2011*, pp. 95–99, China, August 2011.

[9] J. Kong, M. Gerla, and S. Zhou, *Challenges: Building Scalable and Distributed Underwater Wireless Sensor Networks (UWSNs) for Aquatic Applications*, 2005.

[10] S. Basagni, C. Petrioli, R. Petroccia, and M. Stojanovic, "Optimized packet size selection in underwater wireless sensor network communications," *IEEE Journal of Oceanic Engineering*, vol. 37, no. 3, pp. 321–337, 2012.

[11] S. Basagni, C. Petrioli, R. Petroccia, and M. Stojanovic, "Optimizing network performance through packet fragmentation in multi-hop underwater communications," in *Proceedings of the OCEANS'10 IEEE Sydney, OCEANSSYD 2010*, pp. 1–7, Australia, May 2010.

[12] S. Basagni, C. Petrioli, R. Petroccia, and M. Stojanovic, "Choosing the packet size in multi-hop underwater networks," in *Proceedings of the OCEANS'10 IEEE Sydney, OCEANSSYD 2010*, pp. 1–9, Australia, May 2010.

[13] M. Ayaz, L. T. Jung, A. Abdullah, and I. Ahmad, "Reliable data deliveries using packet optimization in multi-hop underwater sensor networks," *Journal of King Saud University - Computer and Information Sciences*, vol. 24, no. 1, pp. 41–48, 2012.

[14] N. Li, J.-F. Martínez, J. M. M. Chaus, and M. Eckert, "A survey on underwater acoustic sensor network routing protocols," *Sensors*, vol. 16, no. 3, p. 414, 2016.

[15] M. Faheem, G. Tuna, and V. C. Gungor, "QERP: Quality-of-Service (QoS) Aware Evolutionary Routing Protocol for Underwater Wireless Sensor Networks," *IEEE Systems Journal*, 2017.

[16] C. Zidi, F. Bouabdallah, and R. Boutaba, "Routing design avoiding energy holes in underwater acoustic sensor networks," *Wireless Communications and Mobile Computing*, vol. 16, no. 14, pp. 2035–2051, 2016.

[17] N. Z. Zenia, M. Aseeri, M. R. Ahmed, Z. I. Chowdhury, and M. Shamim Kaiser, "Energy-efficiency and reliability in MAC and routing protocols for underwater wireless sensor network: A survey," *Journal of Network and Computer Applications*, vol. 71, pp. 72–85, 2016.

[18] I. F. Akyildiz, D. Pompili, and T. Melodia, "Underwater acoustic sensor networks: research challenges," *Ad Hoc Networks*, vol. 3, no. 3, pp. 257–279, 2005.

[19] I. F. Akyildiz, D. Pompili, and T. Melodia, "Challenges for efficient communication in underwater acoustic sensor networks," *SIGBED Review*, vol. 1, no. 2, pp. 3–8, 2004.

[20] C. Peach and A. Yarali, "An Overview of Underwater Sensor Networks," in *Proceedings of the routing techniques regarding network layer*, pp. 31–36, 2013.

[21] I. F. Akyildiz, D. Pompili, and T. Melodia, "State-of-the-art in protocol research for underwater acoustic sensor networks," in *Proceedings of the 1st ACM International Workshop on Underwater Networks*, pp. 7–16, ACM, September 2006.

[22] D. H. Cato, "Ocean ambient noise: Its measurement and its significance to marine animals," in *Proceedings of the Conference on Underwater Noise Measurement, Impact and Mitigation*, pp. 1–9, Institute of Acoustics, Southampton, UK, 2008.

[23] E. J. Harland, SAS. Jones, and T. Clarke, "SEA 6 Technical report: Underwater ambient noise," A report by QinetiQ as part of the UK Department of Trade and Industrys offshore energy Strategic Environmental Assessment programme, 2005.

[24] M. Stojanovic, "Underwater acoustic communications: design considerations on the physical layer," in *Proceedings of the 5th Annual Conference on Wireless on Demand Network Systems and Services (WONS '08)*, pp. 1–10, January 2008.

[25] K. A. Perrine, K. F. Nieman, T. L. Henderson, K. H. Lent, T. J. Brudner, and B. L. Evans, "Doppler estimation and correction for shallow underwater acoustic communications," in *Proceedings of the 44th Asilomar Conference on Signals, Systems and Computers, Asilomar 2010*, pp. 746–750, USA, November 2010.

[26] X. Zhang, X. Han, J. Yin, and X. Sheng, "Study on Doppler effects estimate in underwater acoustic communication," in *Proceedings of the ICA 2013 Montreal*, pp. 070062-070062, Montreal, Canada, 2013.

[27] M. Garcia, S. Sendra, G. Lloret, and J. Lloret, "Monitoring and control sensor system for fish feeding in marine fish farms," *IET Communications*, vol. 5, no. 12, pp. 1682–1690, 2011.

[28] C. Lv, S. Wang, M. Tan, and L. Chen, "UA-MAC: An underwater acoustic channel access method for dense mobile underwater sensor networks," *International Journal of Distributed Sensor Networks*, vol. 2014, Article ID 374028, 2014.

[29] S. Shahabudeen, M. Chitre, and M. Motani, "Adaptive multimode medium access control for underwater acoustic networks," *IEEE Journal of Oceanic Engineering*, vol. 39, no. 3, pp. 500–514, 2014.

[30] A. Sehgal, I. Tumar, and J. Schönwälder, "Variability of available capacity due to the effects of depth and temperature in the underwater acoustic communication channel," in *Proceedings*

*of the OCEANS '09 IEEE Bremen: Balancing Technology with Future Needs*, Germany, May 2009.

[31] A. F. Harris III, D. G. B. Meneghetti, and M. Zorzi, "Maximizing channel utilization for underwater acoustic links," in *Proceedings of the OCEANS 2007 - Europe*, pp. 1–6, June 2007.

[32] Y. Guo and Y. Liu, "Localization for anchor-free underwater sensor networks," *Computers and Electrical Engineering*, vol. 39, no. 6, pp. 1812–1821, 2013.

[33] X.-J. Du, K.-J. Huang, S.-L. Lan, Z.-X. Feng, and F. Liu, "LB-AGR: level-based adaptive geo-routing for underwater sensor network," *The Journal of China Universities of Posts and Telecommunications*, vol. 21, no. 1, pp. 54–59, 2014.

[34] C.-J. Huang, Y.-W. Wang, H.-H. Liao, C.-F. Lin, K.-W. Hu, and T.-Y. Chang, "A power-efficient routing protocol for underwater wireless sensor networks," *Applied Soft Computing*, vol. 11, no. 2, pp. 2348–2355, 2011.

[35] T. Ali, L. T. Jung, and I. Faye, "Diagonal and Vertical Routing Protocol for Underwater Wireless Sensor Network," *Procedia - Social and Behavioral Sciences*, vol. 129, pp. 372–379, 2014.

[36] J. Lloret, S. Sendra, M. Ardid, and J. J. P. C. Rodrigues, "Underwater wireless sensor communications in the 2.4 GHz ISM frequency band," *Sensors*, vol. 12, no. 4, pp. 4237–4264, 2012.

[37] B. Z. Chen and D. Pompili, "Reliable geocasting for random-access underwater acoustic sensor networks," *Ad Hoc Networks*, vol. 21, pp. 134–146, 2014.

[38] L. T. Jung and A. B. Abdullah, "Underwater wireless network: Energy efficiency and optimal data packet size," in *Proceedings of the 1st International Conference on Electrical, Control and Computer Engineering 2011, InECCE 2011*, pp. 178–182, Malaysia, June 2011.

[39] S. Gopi, K. Govindan, D. Chander, U. B. Desai, and S. N. Merchant, "E-PULRP: energy optimized path unaware layered routing protocol for underwater sensor networks," *IEEE Transactions on Wireless Communications*, vol. 9, no. 11, pp. 3391–3401, 2010.

[40] T. Hu and Y. Fei, "QELAR: a machine-learning-based adaptive routing protocol for energyefficient and lifetime-extende d underwater sensor networks," *IEEE Transactions on Mobile Computing*, vol. 9, no. 6, pp. 796–809, 2010.

[41] M. Ayaz, A. Abdullah, I. Faye, and Y. Batira, "An efficient dynamic addressing based routing p rotocol for underwater wireless sensor networks," *Computer Communications*, vol. 35, no. 4, pp. 475–486, 2012.

[42] H. Yan, Z. J. Shi, and J.-H. Cui, "DBR: Depth-Based Routing for underwater sensor networks," in *NETWORKING 2008 Ad Hoc and Sensor Networks, Wireless Networks, Next Generation Internet*, vol. 4982 of *Lecture Notes in Computer Science*, pp. 72–86, Springer, 2008.

[43] M. R. Jafri, M. M. Sandhu, K. Latif, Z. A. Khan, A. U. H. Yasar, and N. Javaid, "Towards delay-sensitive routing in underwater wireless sensor networks," in *Proceedings of 5th International Conference on Emerging Ubiquitous Systems and Pervasive Networks*, vol. 37, pp. 228–235, Canada, September 2014.

[44] S. Zhang, D. Li, and J. Chen, "A link-state based adaptive feedback routing for underwater acoustic sensor networks," *IEEE Sensors Journal*, vol. 13, no. 11, pp. 4402–4412, 2013.

[45] Z. Guo, G. Colombi, B. Wang, J. H. Cui, D. Maggiorinit, and G. P. Rossi, "Adaptive routing in underwater delay/disruption tolerant sensor networks," in *Proceedings of the 5th Annual Conference on Wireless on Demand Network Systems and Services (WONS '08)*, pp. 31–39, January 2008.

[46] Y.-S. Chen and Y.-W. Lin, "Mobicast routing protocol for underwater sensor networks," *IEEE Sensors Journal*, vol. 13, no. 2, pp. 737–749, 2013.

[47] Z. Li, N. Yao, and Q. Gao, "Relative Distance Based Forwarding Protocol for Underwater Wireless Networks," *International Journal of Distributed Sensor Networks*, pp. 1–11, 2014.

[48] S. K. Dhurandher, M. S. Obaidat, and M. Gupta, "A novel geocast technique with hole detection in underwater sensor networks," in *Proceedings of 2010 ACS/IEEE International Conference on Computer Systems and Applications, AICCSA 2010*, Tunisia, May 2010.

[49] Y. Noh, U. Lee, P. Wang, B. S. C. Choi, and M. Gerla, "VAPR: void-aware pressure routing for underwater sensor networks," *IEEE Transactions on Mobile Computing*, vol. 12, no. 5, pp. 895–908, 2013.

[50] S. Basagni, C. Petrioli, R. Petroccia, and D. Spaccini, "Channel-aware routing for underwater wireless networks," in *Proceedings of the OCEANS 2012 MTS/IEEE - YEOSU*, pp. 1–9, May 2012.

[51] A. Wahid and D. Kim, "An Energy Efficient Localization-Free Routing Protocol for Underwater Wireless Sensor Networks," *International Journal of Distributed Sensor Networks*, vol. 2012, Article ID 307246, 11 pages, 2012.

[52] F. Thomsen, "Assessment of the environmental impact of underwater noise," *OSPAR Commission. Biodiversity Series*, 2009.

[53] A. Rahman, V. Muthukkumarasamy, and E. Sithirasenan, "The analysis of temperature, depth, salinity effect on acoustic speed for a vertical water column," in *Proceedings of the 9th IEEE International Conference on Distributed Computing in Sensor Systems, DCoSS 2013*, pp. 310–312, USA, May 2013.

[54] M. Garcia-Pineda, S. Sendra, M. Atenas, and J. Lloret, "Underwater wireless ad-hoc networks: A survey," *Mobile ad hoc Networks: Current Status and Future Trends*, pp. 379–411, 2011.

[55] P. P. Kumar, R. Bhagat, and S. Suvarna, *Underwater Channel Simulation*, PRATHEEK, 2017.

[56] K. V. Mackenzie, "Nine-term equation for sound speed in the oceans," *The Journal of the Acoustical Society of America*, vol. 70, no. 3, pp. 807–812, 1981.

[57] M. Stojanovic, "On the relationship between capacity and distance in an underwater acoustic communication channel," *ACM SIGMOBILE Mobile Computing and Communications Review*, vol. 11, no. 4, pp. 34–43, 2007.

[58] H. Jindal, S. Saxena, and S. Singh, "Challenges and issues in underwater acoustics sensor networks: A review," in *Proceedings of the 2014 3rd IEEE International Conference on Parallel, Distributed and Grid Computing, PDGC 2014*, pp. 251–255, India, December 2014.

[59] E. Felemban, F. K. Shaikh, U. M. Qureshi, A. A. Sheikh, and S. B. Qaisar, "Underwater sensor network applications: a comprehensive survey," *International Journal of Distributed Sensor Networks*, vol. 2015, Article ID 896832, 2015.

[60] H.-P. Tan, R. Diamant, W. K. G. Seah, and M. Waldmeyer, "A survey of techniques and challenges in underwater localization," *Ocean Engineering*, vol. 38, no. 14-15, pp. 1663–1676, 2011.

[61] M. Khalid, Z. Ullah, N. Ahmad et al., "A survey of routing issues and associated protocols in underwater wireless sensor networks," *Journal of Sensors*, vol. 2017, Article ID 7539751, 17 pages, 2017.

[62] M. Ayaz, I. Baig, A. Abdullah, and I. Faye, "A survey on routing techniques in underwater wireless sensor networks," *Journal of Network and Computer Applications*, vol. 34, no. 6, pp. 1908–1927, 2011.

[63] G. Han, J. Jiang, N. Bao, L. Wan, and M. Guizani, "Routing protocols for underwater wireless sensor networks," *IEEE Communications Magazine*, vol. 53, no. 11, pp. 72–78, 2015.

[64] E. M. Sozer, M. Stojanovic, and J. G. Proakis, "Underwater acoustic networks," *IEEE Journal of Oceanic Engineering*, vol. 25, no. 1, pp. 72–82, 2000.

[65] M. P. Malumbres, P. P Garrido, C. T. Calafate, and J. Oliver, *Underwater Wireless Networking Technologies*, Miguel Hernandez University, Spain Technical University of Valencia, Valencia, Spain, 2009.