Study On Underwater Wireless Sensor Network

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APPROVAL

The thesis paper titled “Study on Underwater Wireless Sensor Network” submitted by Anika Barsat (2016- 2-50-016) and Santa Islam (2016-2-50-015) to the Department of Electronics & Communications Engineering, East West University, Dhaka, Bangladesh has been accepted as satisfactory for the partial fulfillment of the requirements for the degree of Bachelor of Science in Information and Communications Engineering and approved as to its style and contents.

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DECLARATION

We hereby, declare that the work presented in this thesis paper is the outcome of the investigation performed by us under the supervision of Dr. Mohammad Arifuzzaman, Assistant Professor, Department of Electronics & Communications Engineering, East West University, Dhaka, Bangladesh. We also declare that no part of this thesis paper and thereof has been or is being submitted elsewhere for the award of any degree or diploma and that all sources are acknowledged.

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This paper is dedicated

To

Our beloved parents and honorable teachers

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First and foremost, I honor and thank the Almighty Allah, for His showers of blessings during my thesis work in order to successfully complete the study.

We would like to express our sincere gratitude to our supervisor Dr. Mohammad Arifuzzaman. Without his encouragement and guidance this study would not have been completed. During the time of this research, we would like to express our appreciation for his guidance, continuous motivation, useful discussions and careful analysis. His keen sight and a wealth of farsighted guidance and supervision have always provided us with this research's specific guiding frameworks. We would also like to thank him for his friendship, empathy, and great sense of humor. Through our research, we learned from him many valuable lessons and concepts about Underwater Sensor Network which we used to improve our ability to function innovatively and to boost my knowledge. His relentless encouragement gave us the confidence to do our work.

Last but not the least, we are immensely thankful to our parents for their devotion, prayers, care and their sacrifices to train and prepare us for our future. Their unconditional support made it possible for us to finish this thesis.

ABSTRACT

The Earth is a water planet whose two-thirds are covered by water. Through rapid technical advances, underwater communication has become an increasingly growing sector where Underwater wireless sensor networks (UWSNs) are a class of emerging networks with variable and high delays in propagation, and restricted bandwidth available [4].

In this thesis we introduce a new Underwater Wireless Sensor Network platform to be used for long term monitoring unlike previous milestone research, follows a rather chronological organization within the given physical layer communication means i.e. acoustic communication, and Electromagnetic spectrum, particularly the Free space optical communication (through Laser or LED) underwater. For each part of UWSNs, we provide a comprehensive presentation of the basic concept, a discussion on the enhancements and variants on that concept**.**

The objective of this study is to provide the big picture of underwater wireless sensor network while simultaneously focus on the details of development of the underwater communication technology (both theory and practice) and their feasibility for adopting in underwater wireless sensor networks. We also discuss various communication methodologies and challenges, underwater sensor network architecture, high level architecture of UWSNs, communication channel characteristics of protocol families for UWSNs, prototypes and relevant hardware for UWSNs and underwater communication, anticipated leverage architecture and discuss the possible competent modulation technique and suitable protocol**.**

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INTRODUCTION

1.1 Wireless Sensor Network

Wireless Sensor Network (WSN) refers to a network of spatially distributed and dedicated sensors to track and record environmental physical conditions and to coordinate the data collected at a central location. WSNs calculate the environmental factors such as temperature, sound, levels of emissions, humidity, wind, etc. [1]. A sensor network consists of a group of small, usually battery-powered devices and wireless infrastructure that track and record conditions in any number of environments-from the factory floor to the data center to a hospital lab and even out in the wild. The sensor network links to the Internet, a WAN or LAN enterprise or a specialized industrial network so that the collected data can be transmitted to analytical back-end systems and used in applications [2]. Most sensor devices in a WSN use long multihop paths to transmit their data to the BS. Therefore in between nodes in a long multi-hop path their individual data must be forwarded to sink as well as transmitted data from other nodes to sink. Such nodes expended energy faster than nodes near the boundary [3].

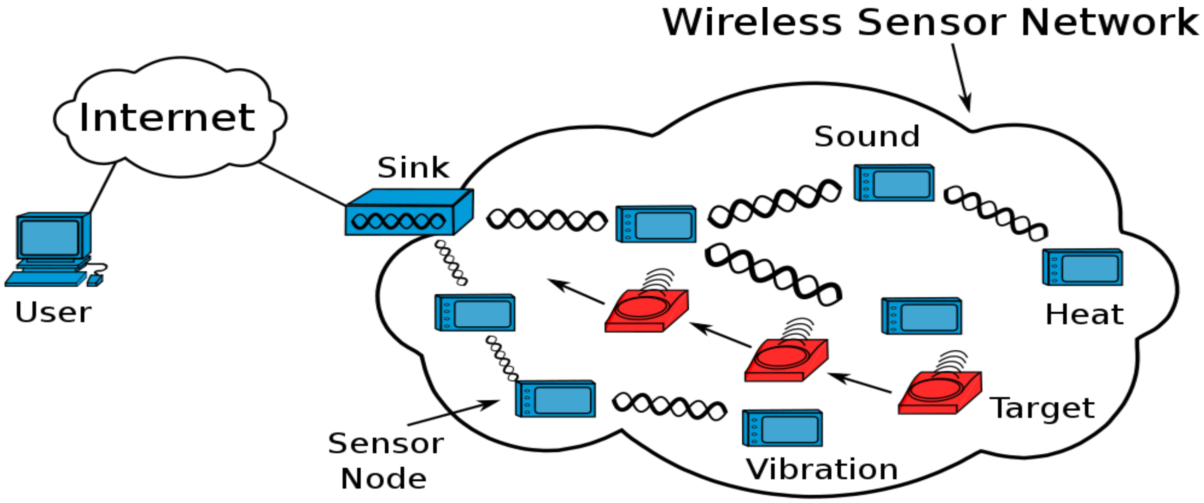

Figure 1. 1 Wireless sensor network

1.2 What is Underwater Wireless Sensor Network

Underwater wireless sensor networks (UWSNs) are a class of emerging networks with variable and high delays in propagation, and restricted bandwidth available. UWSNs has more appeal compared with ground- networks due to its distinctive features and robust applications. UWSNs are very useful in ocean exploration and are very important in military applications [4].

Underwater wireless sensor networks (UWSNs) can also be used for several other applications which are significant.
Such as –

- **a)** Underwater water oilfield monitoring i.e., frequent seismic monitoring and timely feedback in oil extraction.
- **b)** Natural calamity like Tsunami and earthquake monitoring.
- **c)** Collect and analyze data related to bio-diversity underwater.
- **d)** Provide assistance to divers/ communication with divers.
- **e)** Real-time/offline 3D event monitoring under ocean.

1.3 A Brief History of UWSN

Collection of research work in this field has been performed over the last decade. Many of them focus acoustic communication as the only form of practicable underwater communication. The communication protocols are therefore also suggested or developed based on acoustic communication underwater. Marine creatures have possibly used the underwater sound for millions of years. The science of underwater acoustics started in 1490, when Leonardo da Vinci wrote, “If you cause your ship to stop and place the head of a long tube in the water and place the outer extremity to your ear, you will hear ships at a great distance from you.” In 1687 Isaac Newton wrote his Natural Philosophy Mathematical Principles which included the first mathematical treatment of sound [5].

Daniel Colladon, a Swiss physicist, and Charles Sturm, a French mathematician, took the next significant step in the advancement of underwater acoustics. They measured the time elapsed between a burst of light and the sound of a submerged ship's bell heard using an underwater listening horn on Lake Geneva, in 1826.They measured a sound speed of 1435 meters per second over a distance of 17 kilometers (km) providing the first objective measurement of sound speed in water. The result obtained was within approximately 2% of the generally accepted values. In 1877 Lord Rayleigh wrote Sound Theory and developed the theory of modern acoustics [5].

Titanic's sinking in 1912 and the beginning of World War I provided the impetus for the next phase of underwater acoustic development. Developed iceberg tracking and U-boat tracking devices. A number of echolocation patents were issued in Europe and the US between 1912 and 1914, resulting in the echo-ranger of Reginald A. Fessenden in 1914.The first scientific paper on underwater acoustics was published in 1919, theoretically explaining the refraction of sound waves created in the ocean by gradients of temperature and salinity. The paper's range forecasts were experimentally tested by measurements of the propagation loss [5].

The next two decades saw the development of a variety of underwater acoustics applications. During the 1920s the fathometer, or depth sounder, was commercially produced. The transducers used originally natural materials but the 1930s sonar systems using piezoelectric transducers made from synthetic materials were used for passive listening systems and for active echo- ranging systems. These devices were used by both submarines and anti-submarine vessels to allow good effect during World War II. There were several developments in underwater acoustics that were outlined later in the 1946 paper series Physics of Sound in the Sea. The development of sonar systems was mainly motivated by the Cold War after World War II, resulting in advances in the theoretical and practical understanding of underwater acoustics, aided by computer-based techniques [5].

However, few recent works also acknowledge the candidacy of radio frequency optical communication and use as an underwater communication intended. And it has also suggested several effective methodologies and algorithms. In the last few decades of the 20th century, and the early 21st century, wireless communication technologies proliferated and became important quite quickly. A significant factor in the proliferation of wireless devices and systems has been the widespread introduction of radio-frequency technologies. Carl Friedrich Gauss invented the heliograph in 1810 that uses a pair of mirrors to direct a guided sunlight beam to a distant station. Although the original heliograph was designed for the geodetic survey, during the late 19th and early 20th centuries it was used extensively for military purposes. Alexander Graham Bell invented the Photophone, the first portable telephone device in the world, in 1880. After Bell's time military interest in photophones persisted [6].

For example, the German Army created a photophone in 1935, where a tungsten filament lamp was used as a light source with an IR transmitting filter. Current OWC uses as transmitters either lasers, or light emitting diodes (LEDs). MIT Lincoln Labs developed an experimental OWC bridge using a light emitting GaAs diode in 1962 and was able to transmit television signals over a 30-mile radius. Following the laser development, OWC was conceived as the main laser deployment area and several experiments were performed using various types of lasers and modulation schemes. However, the results were generally disappointing due to the broad divergence of laser beams and the inability to manage atmospheric effects. These became the obvious alternative for long distance optical transmission with the introduction of low-loss fiber optics in the 1970s, and moved the emphasis away from OWC systems [6].This study offers a comprehensive overview of current literature and state-of - the-art on the underwater sensor network in line with the direction of real-time monitoring of incidents, processing of data and images via the underwater sensor network.

1.4 Related Work

Earlier, many issues related to the underwater wireless sensor network were discussed such as a novel routing protocol providing good transmission reliability in underwater sensor network which was proposed a routing protocol called LARP for UWSNs that used node location information to convey a message, underwater sensor networks: A review of recent issues and challenges covered many underwater sensor networking techniques. The goal of the techniques reviewed was to overcome the underwater challenges and to provide guidance for future researchers, communication architecture for underwater wireless sensor network compared different methods of communication (radio, optical and acoustic waves) to determine which one suits best in a watery environment, a survey of existing medium access control (MAC) for underwater wireless sensor network (UWSN) which was primarily aimed at providing underwater wireless sensor network (UWSN) with reliable data delivery via RF electromagnetic communication. Also, many others have worked on issues related to the underwater wireless sensor network but our topic do not describe any specific part of underwater wireless sensor network, it discussed overall view of underwater wireless sensor network.

CHAPTER 2

COMMUNICATION METHODOLIGES AND POSSIBLE CHALLENGES

2.1 Introduction

For wireless communication, we can use different communication technologies (radio, optical and acoustic). Propagation medium largely influences characteristics of communication technologies. Communication models used for terrestrial networks cannot be used in underwater environment because new sort of challenges is offered by underwater environment. In this chapter, we will discuss different ways of wireless communication and possible challenges faced by them in water [7].

2.2 Radio Waves

Radio wave is a type of electromagnetic frequency ranging from 3KHz to 300GHz and moving from 100Km to 1 mm. It is named because it includes energy in both magnetic and electric fields. Radio waves travel with speed of light (3×10^8m/s) in vacuum and slow down when travel through a medium according to medium properties. Doppler Effect (change in duration and shift in frequency during propagation of signal from transmitter to receiver in a mobile environment) is negligible in radio waves because high speed of radio wave leads to small duration of transmission. Nonetheless, signal wavelength is inversely proportional to frequency so high frequency radio waves travel very short distances and they are useless for long distance transmission. Wavelength decreases further with the conductive aspect of sea water. Pure water acts as an insulator but heterogeneities present in water (such as salinity and temperature) make it partial conductor. Very low radio frequencies (3-30KHz) can penetrate up to 20 meters deep. Low radio wave penetration level and very short distance of propagation limit its use in water. Attenuation is directly proportional to square root of frequency and conduction of medium [7].

Therefore, for underwater communication, high frequency radio waves lose their power very easily and infeasibly. Absorption losses are directly dependent on the frequency, distance and chemical properties of the propagating medium, meaning that radio waves are easily absorbed by water due to their high frequency band (while transmission wave energy is converted into other forms depending on the propagation of medium elasticity and artifacts in the way). Absorption failure has a detrimental effect on the signal and results in tremendous loss of signal power, transmission range effects and quality controls of the received signal. In fact, electromagnetic waves can be transmitted from water to air and crossing boundaries further decreases the frequency of the waves. In addition, radio waves are capable of raising signal intensity across borders from water to air, and crossing boundaries further. Multi-path effect (multiple occurrences of the same signal) is lower in radio waves due to high attenuation and slight reflections from the sea surface and the sea bed [7].

While radio waves give some great advantages in terms of high frequencies, due to heavy absorption loss and attenuation, broad propagation speed and short period yet high frequency radio waves are impracticable for communication in water. They can only be used at low frequencies but they suffer from their own disadvantages such as restricted bandwidth and extremely short duration of propagation. Reduced bandwidth also limits data transfer speeds and facilitates very low-capacity traffic. In the case of a radio wave, one potential way to achieve contact over longer distances is to relay data from water to air on the side of the transmitter and from air to water on the side of the receiver. It enables transmission over longer distances but involves water to air refraction loss and limits depth of sender as well as receiver [7].

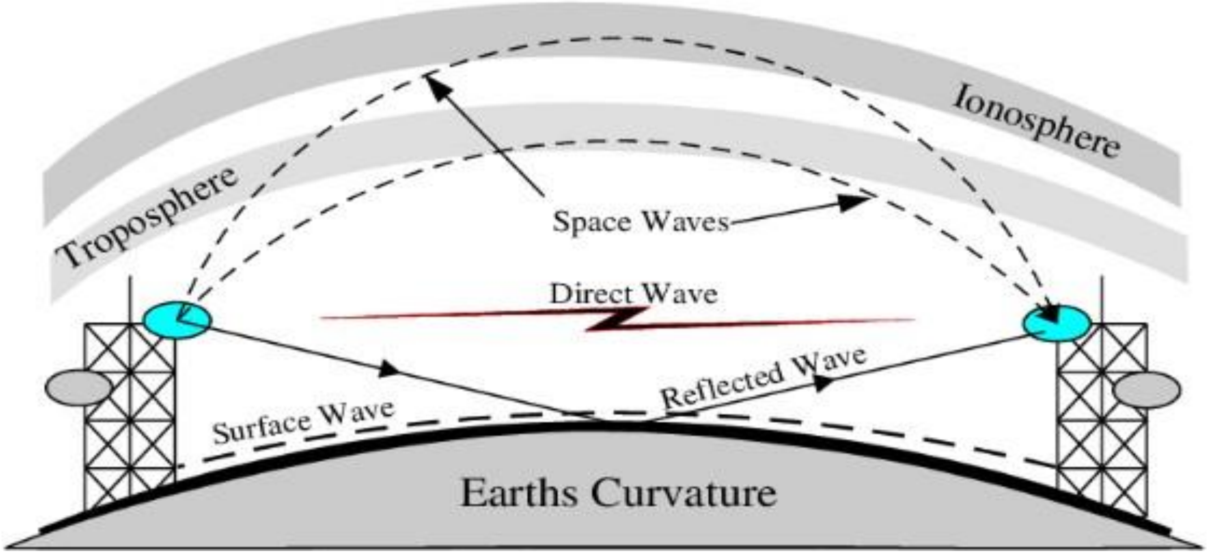

Figure 2. 1 Radio Waves

2.3 Optical Waves

Optical signals range between 400THz and 900THz. As with radio frequencies, higher optical wave frequencies achieve high transmission rate and low power consumption but suffer from the drawback of limited propagation distance. They can travel only from single meters to tens of meters which also have high transmission capacity. Due to absorption and reemission the speed of optical waves in water is 3⁄4 of the speed of light in the vacuum. Optical waves can relay data well beyond radio signals and have very high transmission speeds [7].

This benefit is especially significant in applications that in a short time period require regular exchange of messages over a limited distance. Doppler effect is marginal with high speed of optical waves because propagation length is short so the chances of frequency change became very low. Like radio waves, because of their high frequency band, optical waves have suffered tremendous absorption loss in water, and it is one of the major factors preventing the dissemination of optical waves in water. High frequency optical waves also induce a high attenuation level. Attenuation is a very significant issue for optical frequencies due to their high frequency range [7].

Scattering is yet another significant cause of underwater optical wave loss. Scattering results in a loss of energy of the initial signal as it represents a large amount of energy during dispersal. This phenomenon is known as backscattering, and it could be noise source. Water heterogeneities (particles of sediment, marine organisms, various dissolved salts and mineral particles in ships 'suspension or navigation, etc.) disperse the wave from a straight trajectory, particularly in high frequency cases. Including absorption and vibration, the loss of energy is directly proportional to the turbidity. Different optical modems for underwater communication are also not usable. Optical waves often need line of sight and clear visibility for contact between sender and receiver to reduce the scattering effect and increase the range of transmission [7].

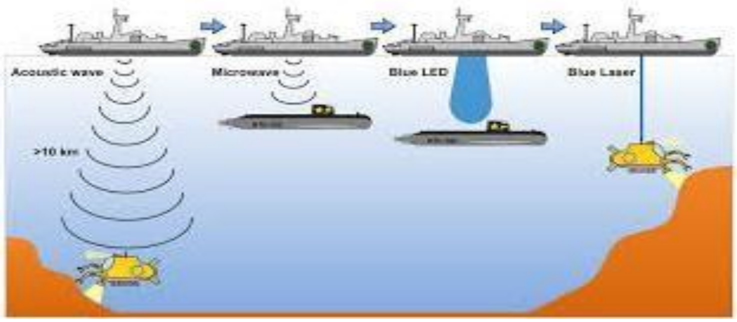

Figure 2. 2 Optical Waves

2.4 Acoustic Wave

Sound (acoustic) waves are considered primary carrier of information transmission in underwater mainly due to low frequency band (20Hz-20KHz). The acoustic wave propagates very rapidly in liquids, rather than air. In air, sound speed is 343.2meter / second where as in the case of acoustic wave fluid propagation speed is 1480 meter / second i.e., acoustic waves propagate 4.3 times faster in water compared with air. In fact, the amplitude of the acoustics decreases with water depth. The effect of the low frequencies is less attenuation. In the case of an acoustic wave, losses from attenuation are very small. Low frequency acoustic wave band can relay data for up to a few kilometers. Yet with restricted bandwidth, the acoustic waves are again confined. Therefore, the optimal usage of bandwidth is a big concern for underwater channels [7].

Multipath effect is more pronounced in acoustic waves due to the high amount of sea surface and seabed reflections and the inability to touch water boundaries through waters. Refraction (change in signal direction) distorts the course of propagation of the acoustic waves because of their slow speed. Slow speed of acoustic propagation in water and multipath phenomenon increases average propagation time for data transmission. Reflecting acoustic wave from top and bottom of water further increases transmission time. Propagation speed is very small with acoustic waves, so length is long [7].

Doppler influence is important in acoustics. Absorption is the most important factor which limits us to use low water frequencies. Absorption failure has an effect on signal attenuation. Low frequency acoustic waves undergo small loss of absorption. Noise is one of the big issues about the efficiency of the transmitted signal when it comes to long distance communication. Whether or not a specific acoustic signal is important is determined by noise level. It is also referred to as the Signal to Noise (SNR) ratio. From the above discussion it is clear that acoustic waves are better suited in underwater setting due to low attenuation, absorption and high data transmission range. All of the above difficulties make getting an identifiable signal without errors difficult. Such problems inspire us to find an integral solution [7].

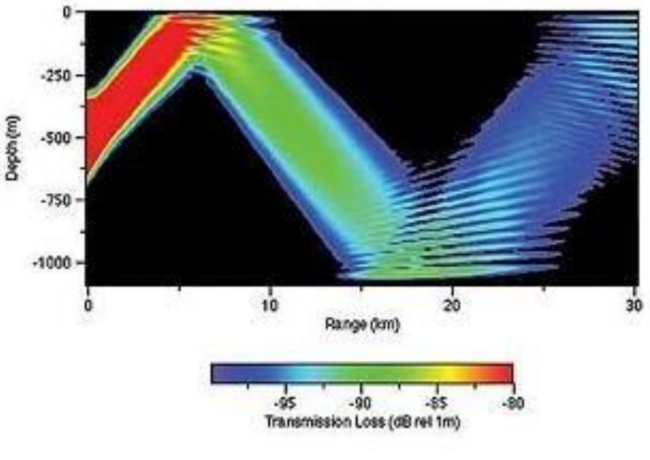

Figure 2. 3 Acoustic Waves

CHAPTER 3

UNDERWATER WIRELESS SENSOR NETWORK ARCHITECTURE

3.1 Introduction

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 it 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 wireless sensor network is an open area for research [8].

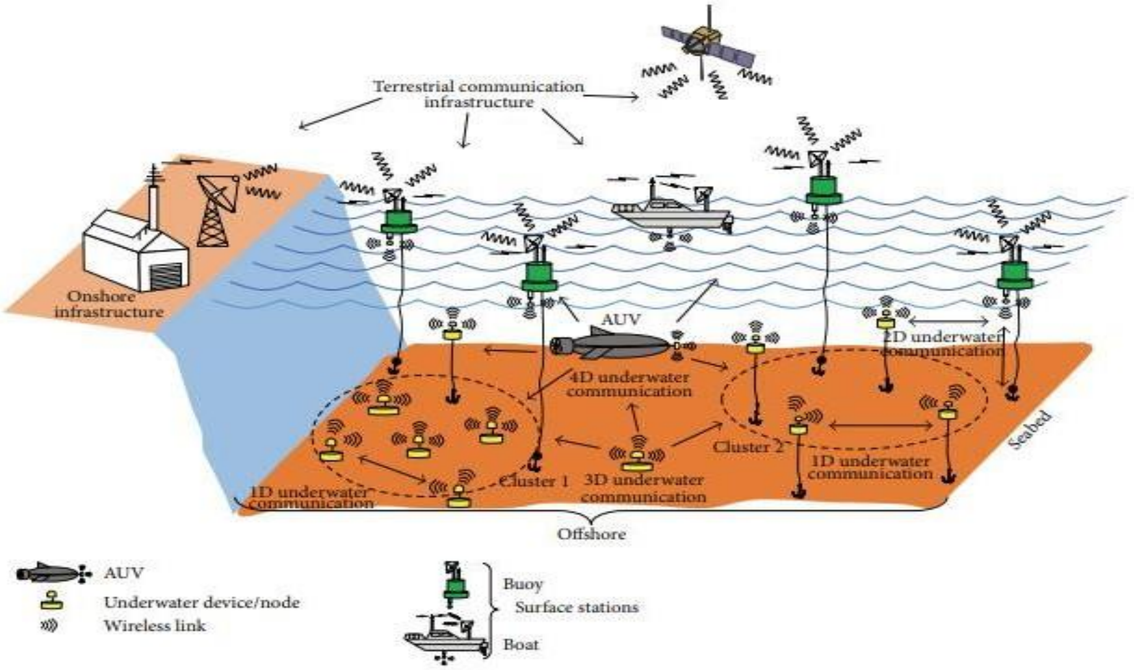

Figure 3. 1 Underwater wireless sensor network architecture

3.2 Underwater wireless sensor networks in one-dimensions

One-dimensional (1D-) UWSN architecture refers to a network with autonomous deployment of the sensor nodes. Each sensor node is itself a stand-alone network responsible for the identification, processing and transmission of information to the remote station. A node in this type of architecture can be a floating buoy that can sense underwater properties or it can be deployed underwater to detect information for a given period of time and then float to the surface to relay sensed information to the remote station. It can be an autonomous underwater vehicle (AUV) that dives, senses or collects the underwater properties within the water, and relays the information to the remote station. The nodes can communicate in 1D-UWSN using acoustics, Radio Frequency (RF), or optical communication. In addition, the topological structure of 1D-UWSN is star where the transmission is carried over a single hop across the sensor node and the remote station [9].

3.3 Underwater wireless 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 issued to send data to command station. Because ocean can be as deep as 10km, vertical transceiver should contain enough range. Surface sink that is equipped with acoustic transceivers has the capability to manage parallel communication, sinks. Surface sink is also equipped through extensive range radio frequency transmitters, to communicate with offshore sinks [8].

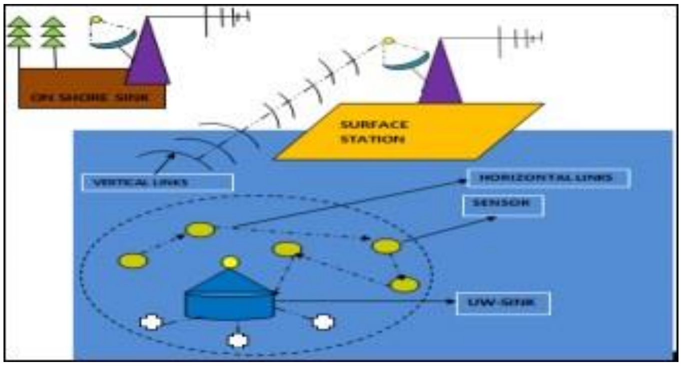

Figure 3. 2 Two-D architecture

3.4 Underwater wireless sensor networks in three-dimensions

Activity required to present three-dimensional environments new architecture which is known as underwater three-dimensional networks issued. Sensor nodes float at different depth to monitor a specific activity in three-dimensional under water networks. Traditional solution regarding underwater three-dimensional sensor networks 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 [8].

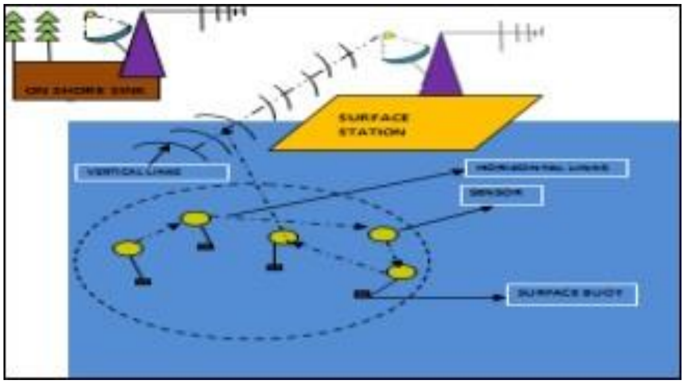

Figure 3. 3 Three-D architecture

3.5 Underwater wireless sensor networks in four-dimensions

Four-dimensional (4D) UWSN is constructed by integrating stationary UWSN, i.e. 3D-UWSN and mobile UWSN. The mobile UWSN consists of remote underwater vehicles (ROVs) for collecting data from the anchor nodes and relaying the data to the remote station. Submersible robots, aircraft, ships, and even submarines may be autonomous. Each underwater sensor node will relay the data directly to ROVs autonomously, depending on how close that particular sensor node is to the ROV. The contact scenario between the ROV and the node of the underwater sensor depends on the distance and data between them, so it is possible to use either acoustic or radio. Since the transmission is to be transmitted directly to ROV, sensors with large data and close to ROVs can use radio connections, while sensors with limited data to transmit or far from ROV can use acoustic links [9].

CHAPTER 4

HIGH LEVEL ARCHITECTURE OF UWSNs

4.1 Classification of High-Level Architecture of UNWSNs

The taxonomy of the UWSN is classified here based on the communication medium that used. Based on that we see 3 types of architecture in the literature

- **a)** UWSN based on acoustic communication
- **b)** UWSN based on wireless optical communication
- **c)** UWSN based on radio frequency.

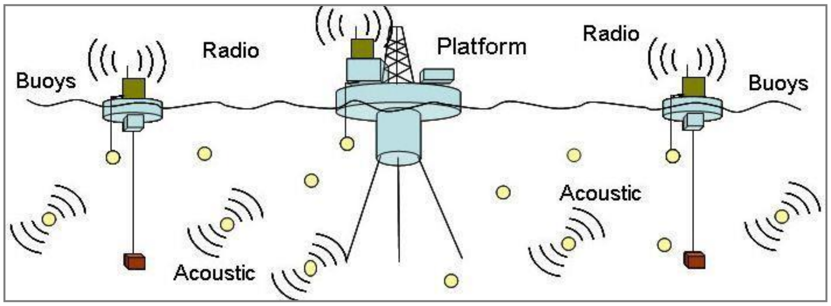

Figure 4. 1 High level view of the architecture of Underwater Acoustic sensor Network

4.1.1 UWSN Based on Acoustic Communication

The technique of sending and receiving messages is known as acoustic communication through the use of sound propagation in underwater environment. Acoustic communication is a very effective form of underwater wireless communication. At the hardware level, the acoustic communication underwater varies in a few main ways from in-the-air RF. In both systems we transmit a tone or carrier that modulates the data, such as amplitude, frequency, or phase modulation. The principal differences between modulation techniques are the sensitivity of the receiver, the necessary bandwidth and the minimum acceptable signal-to-noise ratio (SNR). Normally SNR is expressed as Eb / No, or energy per bit over spectral density of noise. Water is an excellent medium for the transmission of sound [8].

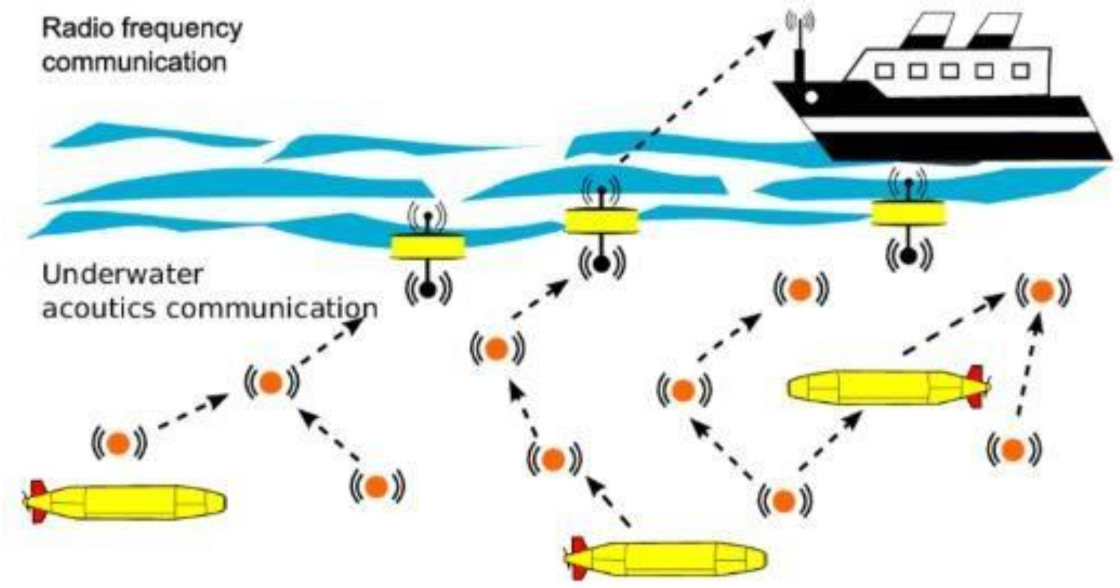

Figure 4. 2 UWSN based on Acoustic Communication

4.1.1.1 Submarine Communication

It was 1940s as we look at the past, when submarine crews used sound to communicate and locate enemy vessels. Following a test sponsored by the ONR (OFFICE OF NAVAL RESEARCH) in 1996, the operational Navy's interest was gradually piqued to the point of launching a Tactical Acoustic Communications Advanced Technology Demonstration (ATD) project. The base project was running for three years and included testing a carry-on acoustic communications system that used the low-frequency (less than 10 kHz) sonar on board a Los Angeles submarine (688) class and a destroyer from Arleigh-Burke. The capability was then built into a processor and software update called advanced fast COTS (commercialization) [10].

With the developments in acoustic modem technology that allowed high-rate, reliable communications, current research focuses on communication within a network environment between different remote instruments. Underwater acoustic (UWA) networks are typically created by acoustically connected ocean-bottom sensors, autonomous underwater vehicles, and a surface station providing a link to an on-shore control center. Although many applications require long-term deployment area monitoring, battery-powered network nodes limit the existence of UWA networks. Advances in digital signal processing (DSP) hardware and techniques have helped make underwater acoustic modems possible resulting in an increased interest in acoustics for underwater communications and underwater wireless sensor network [10].

Figure 4.1 shows the architectural view of the network where we see four different node types. At the lowest layer the large number of sensor nodes (shown as small yellow circles) are installed on the sea floor. They collect data via attached sensors (e.g. seismic) and use short-range acoustic modems to communicate with other nodes. They run on batteries and they spend most of their lives sleeping to work for long periods of time. Numerous deployment strategies are possible for these nodes; here we show them anchored to the sea floor. (Possibly buried for safety as well.). Tethers ensure nodes are located approximately where planned and allow positioning optimization for good sensor coverage and communications coverage. Owing to anchor drift or disruption from external effects node movement is still possible. We expect nodes to be able to determine their locations via distributed algorithms of localization [11].

One or more control nodes with Internet connectivity are located at the top layer. The node shown in Figure 4.1 on the platform is that kind of node. Such control nodes can be installed with power on an off-shore platform, or they can be on-shore; we expect such nodes to have a wide storage capacity for buffering data, and access to sufficient electric power. Control nodes can communicate directly with sensor nodes, by connecting with wires to an underwater acoustic modem. Finally, while robotic submersibles aren't the focus of the current research, we see them communicating with our system through acoustic communication. Throughout the figure, "fishes" throughout dark blue depicts multiple robots [11].

4.1.2 UWSN Based on Optical Wireless Communication

For all communication modes the underwater environment is demanding, with distinct tradeoffs between range and data rate. The high electrical conductivity of seawater attenuates the electromagnetic waves exponentially. Acoustics have a long operating range (kilometers) at low data rates (kilobits / second), but usually have poor output in shallow waters due to ocean noise and numerous surface and bottom acoustic reflections. This causes interference between symbols (signal distortion). Optical underwater free-space (FSO) communications using blue or blue- green lasers and light-emitting diodes (LEDs) include small, short-range (< 150 m), high- bandwidth (megabits / second) solutions with ranges strongly dependent on water quality [12].

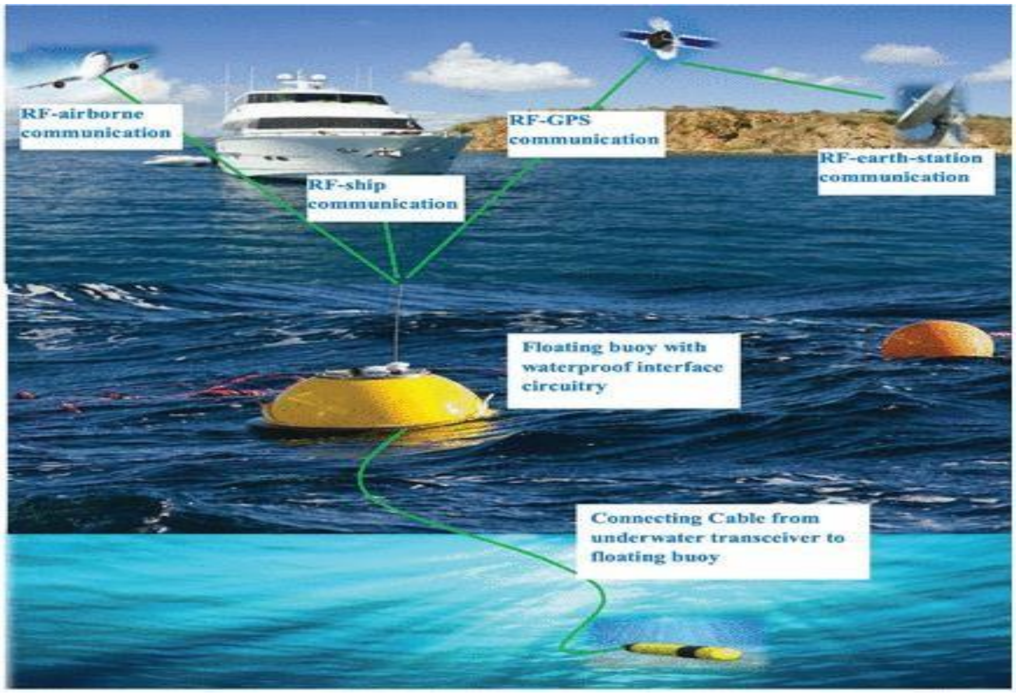

Figure 4. 3 Optical wireless Communication

4.1.2.1 Data Rate Vs. Range

The bandwidth requirements for underwater operations may vary from about 1 kHz for control signals to telemetry, which could require 10 times as much bandwidth for data or imagery transmission. The telephone-quality audio typically requires approximately 3 kHz of bandwidth to provide a frame of reference, whereas compressed video streaming of high-quality needs about 500 Kbit / s. In general, a communication network with optimized radio frequency (RF) approaches around 1 bit / Hz of usable bandwidth, indicating the use of high carrier frequencies. Nevertheless, the penetration of radio waves into water strongly depends on conductivity and frequency, and has historically been limited to very low frequency (VLF) communication with submarines and data levels of 100 bits / s maximum [12].

Recently some modems will transmit at kilobit rates for short distances of a few meters. The typical way underwater vehicles interact has been acoustic. The velocity and attenuation of sound in water depends on frequency, with highly attenuated higher frequencies and inter-symbol interference limiting commercial devices to < 500 Kbit / s. Underwater video is becoming increasingly important for acoustics and is very difficult even when frame rates are reduced and compression algorithms are used. Optical wireless, on the other hand, can transmit easily from 1 to 5 Mbit / s with light-emitting diodes (LEDs) and with diode lasers at gigabit data rates (see Figure 4.4).There have been recent efforts to increase the bandwidth of LEDs that may open additional opportunities for higher-data- rate, LED-based communications [12].

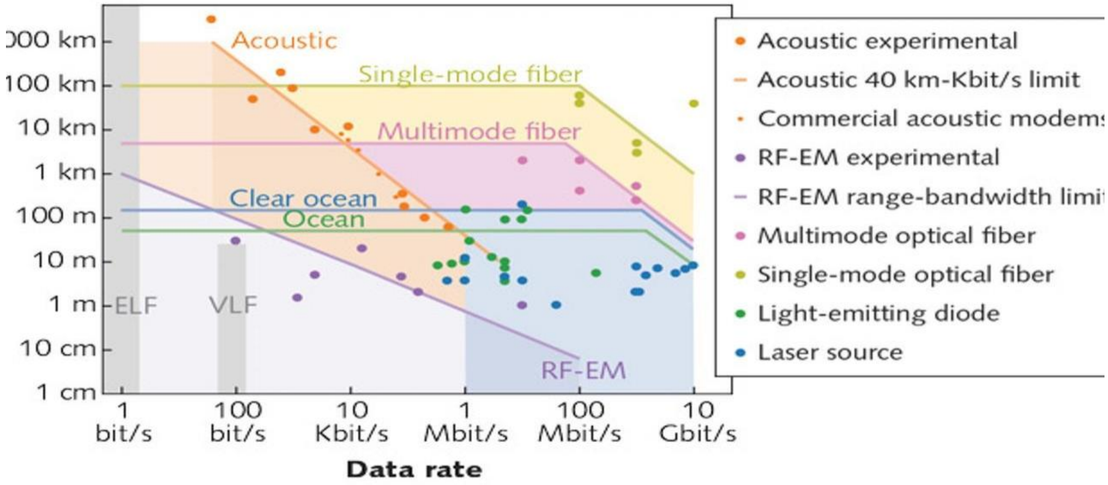

Figure 4. 4 Data rate vs range

Figure 4.4 For effective underwater communication, the light blue region represents where short-range optical communications <150 m will dominate, with data rates easily beyond 1 Mbit/s; the orange regions represent acoustic communications for lower data rates with commercial system ranges up to 10 km. Military applications will continue to use low-data-rate acoustic and RF communications. [12]

4.1.2.2 Going Deep with Optics

There are two possible means of optical communication underwater free space: point-to-point, and laser-coherent communication. Lasers are monochromatic (single color wavelength), collimated (non-divergent) and coherent (wavelengths in- phase) in contrast, LED's are neither coherent nor collimated and generate a broader band of wavelengths (multiple). In addition, a significant difference between the two is the power output. The peak power output of lasers is measured in watts, while that of LED's, is measured in milliwatts. Also, LED's usually have a 50% duty cycle, meaning that they are "on" 50% of the time and "off" 50% of the time regardless of what frequency (pulses per second) setting is used [12].

Structures permanently placed on the seabed can be serviced by underwater fiber-optic cables to provide very high bandwidth communication between subsea nodes at gigabit levels. However, the underwater FSO contact proposition is more complicated compared to the directed modes of optical fibers. Terrestrial FSO systems have bulk optics for reducing beam divergence, strong pointing and tracking systems, and adaptive multi-wavelength optics for managing atmospheric turbulence. At present, these systems can provide gigabit data rates over kilometer-length scales. The use of eye-safe 1,55 µm lasers, erbium fiber amplifiers, and detectors built for fiber-optic communications has greatly improved these capabilities. Since near-infrared (near-IR) wavelengths are heavily absorbed by water, bright blue-green lasers and LEDs have been found to be a problem for underwater communication. Fortunately, high-brightness gallium-nitride (GaN)-based LEDs and diode lasers now provide cheap light sources for small underwater platforms, while frequency-doubled near-IR lasers provide high peak power for larger pulsed systems.

A second problem is that during daylight hours for shallow depths, the sun is a very bright, interfering light source that limits the efficiency of underwater detectors, so good optical filtering and wide dynamic range detectors are required. Finally, turbulence isn't the primary factor in undersea communications networks relative to terrestrial FSO communications. Instead, the main concerns to tackle are absorption and dispersal. Maximum transmission at blue wavelengths (405–440 nm) is achieved in clear-blue ocean water, with the absorption coefficient approximately 0.017 m-1. For coastal waters, the absorption coefficient is nearly twice as much- about 0.033 m-1, with the average transmission changing to green (510–530 nm). The absorption in the most turbid, black-matter-rich coastal water is around 0.291 m-1 with the minimum absorption in the violet. The estimated transmission range for optical wireless communications in the ocean, based on these values, is 150–200 m in very clear ocean waters, 50–75 m in ordinary ocean waters, and just a few meters in turbid harbor water. Unlike acoustics, the scattering dispersion of multipaths is very high and is almost negligible until it operates at data levels greater than 1 Gbit / s [13].

4.1.3 UWSN based on Radio Frequency (RF)

Since the very early days of radio, electromagnetic communications underwater have been studied and again gained significant attention during the 1970s. During this time, terrestrial radio usually offered long-range, manual digital communications (Morse code) or full-bandwidth analog voice communications, and research was aimed at providing those types of underwater service. In addition, it is assumed that the Extremely Low Frequency (ELF) submarine communications system is the only electromagnetic subsea technology that was successfully deployed. This system worked at 76 Hz for the US system and 82 Hz for the Russian system and allowed a few characters per minute to be transmitted across the globe. This introduced a one way "bell ring" that used terrestrial radio to call an individual submarine to the surface for higher bandwidth communications. Analog voice communications were found to be inefficient via water, maximum bandwidth, long range, and there quickly developed a "perceived wisdom" that electromagnetic signals had no applications in the underwater environment. The acoustic modem technology has set a standard for subsea wireless communication links [14].

Acoustic transmissions outperform electromagnetic for vertical range and are the best engineering option in most applications of the longer distances. The technology is now maturing, and the basic operational limitations are well known. Since electromagnetic signaling uses a different method of transmission from the acoustic, the two methods have no overlap in difficult operating conditions. The methods of acoustics and electromagnetics can be used as complementary technologies. In the digital age, we got acquainted with the advantages of short- range, high-bandwidth networking systems like Bluetooth. At the same time the oil industry and military operations have growing requirements that have generated demand for secure, connector less short-range data links. It's time to reassess electromagnetic communication capabilities in the underwater world. An initial analysis found that there were many benefits in electromagnetic communication, combined with digital technology and signal compression techniques, making it ideal for underwater applications in niches [14].

Electromagnetic signals under water have a variety of practical uses in navigation, sensing, and communication. Short range navigation systems may be based on the gradient of signal magnitude shown in the propagation of electromagnetics. Sonar systems may use phase information for beacon applications to sense wave front direction and suffer from multi-path effects and pressure gradients. UUV navigation systems based on electromagnetic signals can measure increased signal intensity as a direct response to a beacon movement allowing a very fast, robust loop control. Distributed cables may be designed to lengthwise radiate an electromagnetic signal. There is no counterpart for this type of distributed transducer in the acoustic domain [14].

A cable allows short navigation range and reduces the range needed for mobile communications. EM technology can provide navigation and telemetry capabilities for subsea applications using different sensing concepts. EM technology has been shown to be incapable of competing with acoustics in terms of range and energy consumption, but it does have modern sensing and communication technologies that are much less environmentally sensitive than acoustic. When higher data rates are required, we should use radio frequency (RF) methods that can achieve communication data rates of up to 100 Mb / s in very short distances, apart from significant immunity from environmental characteristics [14].

Electromagnetic (EM) waves can also be a good choice for wireless communication systems underwater, in the RF range. EM waves in shallow water are less sensitive to the effects of reflections and refractions than acoustic waves. Furthermore, they have very little effect on suspended particles. The amplitude of the EM waves is higher than that of the acoustic ones (150,000 times greater) [14]. The speed of an EM wave depends primarily on the permeability (μ), permittivity (π), conductivity (π) and the density of the loading volume (ÿ). Such parameters differ with the form of water and the electrical conductivity value associated with the medium also varies, thus the wave propagation velocity and the absorption coefficient directly associated with the working frequency often vary [15].

Conductivity provides different values for each case, seawater has a high average conductivity value, which is around 4 S / m (obviously it varies with the salinity and physical properties of each type of seawater), but in fresh water the standard value is 0.01 S / m and drinking water has a conductivity between 0.005 and 0.05 S / m. Additionally, seawater permittivity varies as a function of the size, temperature, and salinity [15].Therefore, the key issue for underwater communication dependent on EM waves is the high attenuation due to the water conductivity. This attenuation increases with increasing frequency of the EM wave. The higher frequencies would therefore show greater losses in the signal [16,17].

The basic advantages of using radio frequency for underwater communication are [16,17]:

a) High speed of propagation
b) Ability to cross water to air boundary
c) Broadband, frequency agile capability
d) Lower Multipath fading
e) For short range, high bandwidth applications bit efficiency is high
f) Immune to acoustic noise
g) No known effects on marine animals
h) Unaffected by low visibility
i) Immune to aerated water
j) Covert, localized communication.

While the disadvantages of using RF, signal are [16,17]:

- **a)** Design complexity of RF transmitter and receiver which are suitable for Underwater communication
- **b)** High power transmission is required
- **c)** Frequency selectivity

CHAPTER 5

COMMUNICATION CHANNELCHARACTERISTICS AND PROTOCOL FAMILIES FOR UWSNs

5.1 Introduction

We cited the protocols here starting for the lowest layer of the OSI reference model.
Many researchers are also focusing for the developments of effective MAC protocols in terms of capacity and reduced consumption of power. Routing strategies that establish efficient data delivery paths in underwater environment is another demanding requirement. Designing of Transport layer protocol for fluctuated aquatic environment is an open research area.

5.2 Physical Layer

In [18], physical layer communication properties in case UWSN are explained. In terms of physical layer, coherent MIMO-OFDM based communication is considered as feasible solution for the band limited/frequency selective underwater channel with more spectral efficiency, high data rates and reliable links. Considering the implications of complicated aquatic channel characteristics (extremely limited bandwidth, noise, Doppler spread, multipath, complex propagation delay). Underwater FSO received substantial attention and become a viable alternative to underwater acoustic communications (UAC) more recently due to higher bandwidth, data rate and security. One of the key challenges of using FSO underwater is to achieve the higher communication distance. In underwater environment, due to absorption and scattering processes the photons lose energy and change propagation direction while interacting with water molecules or suspended particles.

As a result, absorption and scattering properties dominate the propagation behavior of photons in underwater for different constituents of water (i.e., clear water, turbid water, saline water etc.) and affect the corresponding probability distribution, i.e., normalized intensity distribution, in space and time domains. Some prior works have proposed channel models to characterize the propagation behavior of photons and therefore facilitate system design and performance evaluation. Ding et al. proposed a parametric single Gamma function to represent the impulse response of non-line-of-sight (NLOS) ultraviolet multiple scattering channels [19] and then built a path loss model for the NLOS link based upon probability theory governing random migration of photons [20].

However, these models for free space optical links primarily concerned about the **atmospheric channel** hence, may not be applicable for underwater FSO links due to different optical channel properties. For underwater FSO links, channel models have been proposed and evaluated analytically, experimentally and numerically. [21] adopted the vector radiative transfer (VRT) theory to model the underwater optical channel analytically and qualified the scattering effect on the polarization behavior of light in underwater environment. Moreover, Hanson et al. [22] measured temporal pulse broadening over a range of extinction and reported an error-free transmission over ocean water channels. For several tens of meters link range higher data rate [up to 1 Gbit/s] is achieved. For evaluating the correctness of Monte Carlo simulations by experimental tests is performed in [23].

However, the test is performed for very short distance i.e., 12.5 meters water tank. Furthermore, the spatial path loss and temporal impulse response have been investigated based on numerical approaches. [24] developed a numerical tool of Monte Carlo simulation for UWOC links and presented a two-term exponential power loss model. [25], [26] have investigated the temporal impulse response of UWOC systems using the Monte Carlo approach instead of solving the VRT equation. [27] proposes a closed-form expression of double Gamma functions to model the impulse response in turbid water and evaluated the bit-error-rate (BER) and bandwidth for various system geometries. The impulse response and path loss of underwater FSO channel characterize the spatial-temporal behavior of the channels respectively. [28] Proposes a stochastic channel model to represent the spatial-temporal probability distribution of photons during their propagation over underwater FSO channel. However, the stochastic channel model only considers only non-scattering case which is not pragmatic.

Therefore, the model has limited applicable channel parameters and system configurations since multiple scattering tends to be non-ignorable and dominant in more turbid water. In [29], authors focus on the channel impulse response and quantify the channel time dispersion under different conditions of water type, link distance, and transmitter/receiver parameters. However, the study is only simulation based and not validated by the experimental results. In [30], a comprehensive review of the theory necessary to describe spatial spreading of an optical beam in the presence of scattering agents underwater is presented. [31] describes and assesses underwater channel models for optical wireless communication. Models considered are: inherent optical properties; vector radiative transfer theory with the small-angle analytical solution and numerical solutions of the vector radiative transfer equation (Monte Carlo, discrete ordinates and invariant imbedding). In [32], Experimental validation of a Monte Carlo model for determining the temporal response of the underwater optical communications channel.

5.3 Mac Layer

Medium access control (MAC) is an important technique that enables the successful operation of the network. The MAC layer has the objectives of maintaining and monitoring communication channels used by several nodes to prevent collisions and to establish stable conditions of transmission. One fundamental task of the MAC protocol is to avoid collisions from interfering nodes in UWSNs. Active data collection, aggregation and networking to the sites where data can be displayed and interpreted would be the implementation of MAC protocols for the underwater sensor network [33].

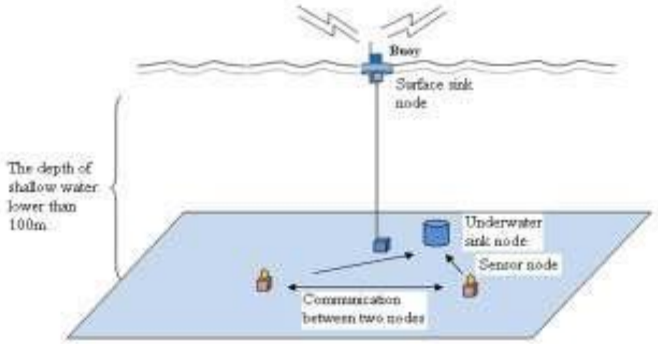

Figure 5. 1 Network Model between Two Nodes in UWSN

The MAC protocol is very important to the underwater sensor network in ensuring reliability of the data. Various applications needed specific MAC Protocol specifications. The goal of this project is to develop a MAC protocol for long-term applications, such as monitoring water quality for agricultural purposes. This application is not sensitive to end-to-end delay because the communication link of UWSN is using RF electromagnetic waves that have high propagation speed which is 3×10^8 m/s. Hence, the propagation delay is very low and can be ignored. For such an underwater sensor network, the most important aim of the MAC protocol is to solve the data packet collision efficiently as regards energy consumption. Another aim of this project's designing MAC protocol is to ensure high network performance, low energy consumption and low channel access latency [33].

An explanation why existing MAC protocol based on terrestrial radio frequency (RF) cannot be used directly at UWSN due to the harsh physical characteristics of the underwater channel. The existing MAC protocol for UWSN currently uses acoustics as a communications source. There is no current MAC protocol that can be adapted via RF electromagnetic connection in UWSN. The velocity of propagation is one big difference between RF and acoustic propagation. As described above, the radio waves fly at the speed of light. Sound velocity in water is about 1500 m / s, and varies considerably with temperature, density, and salinity, allowing sound waves to travel along curved tracks [33].

MAC protocols control access to the means of communication. Collisions of unrequested communications can degrade overall network performance without proper management of the transmitting media. Therefore, the basic purpose of MAC protocols is to avoid collisions. But they do need to tackle other considerations, such as energy consumption, scalability and latency. A collision occurs when two or more frames of data arrive simultaneously at the intended receiver. Standard MAC protocols attempt to tackle this time volatility by, for example, slotting time (Multiple Access Time-Division or TDMA) or sensing the channel before transmission (Multiple Access or CSMA) [34].

Nevertheless, these networks often suffer from space instability due to the long propagation delays of underwater transmission, so it is important to take into account the positions of the receivers so their potential interferers. This problem is generally called spatial-time or spatial- temporal ambiguity in the literature. Another problem which comes with long delays in propagation is spatial injustice. Since the transmission time for the packet depends on the distance to the transmitter, the channel is free at the transmitter first and then at the receiver later. Then nodes closer to the transmitter will reach the channel before nodes closer to the receiver [34].

5.4 Factors Influencing the Design of Underwater Protocol

Communication channels in shallow water have various imperfections due to several factors including shipping noise, multipath, water movement, gradients of density and water non-homogeneity due to solid or gaseous content particles. Of these factors, the time-varying propagation of multipaths and non-Gaussian noise are the two main factors which limit communication in shallow water. Compared to a potential direct line, propagation occurs in shallow water in surface bottom bounces. In fact, the channel properties differ over time due to variations in random signals. Those involve wave-induced surface scattering, which is the most significant contributor to the shallow water channel's overall time variability. Water depth is a serious factor which affects UWSN. The element shaping submarine contact as follows [33]:

a) **Transmission loss:** the primary problem of transmission loss is attenuation and geometric spreading. The attenuation relates primarily to the absorption or conversion of energy into heat. Attenuation of radio waves in water increases with both conductivity increase and frequency rise. Geometric spreading due to the expansion of wave fronts may also disperse the signal energy.

b) **Multipath:** Multipath propagation will significantly degrade the signal. The configuration of the connection like characterization of horizontal channels defines the geometry of multipaths.

c) **Noise:** Environment noises include man-made noise and ambient noise. Man-made noise mainly refers to machinery noise like pumps while natural noise refers to seismic and biological phenomena can cause ambient noise.

d) **Propagation delay and delay variance:** Large propagation delay and high delay variance can be reduced the throughput of the system.

5.5 Network Model in UWSN

Figure 5.1 displays a network layout between two nodes in the UWSN ambient. The network is composed of sensor nodes underwater, sink node underwater and sink node air. Underwater sensor nodes are deployed to the bottom of the controlled area such as ocean and river. Thus, underwater sink nodes are responsible for collecting data from the underwater sensor node deployed on the bottom of the ocean and then sending the data to the sink level. Finally, the surface sink node is connected to a floating buoy with cable, radio frequency (RF) or mobile phone technology to relay data in real time to the shore [33].

CHAPTER 6

PROTOTYPES AND RELEVENT HARDWARE FOR UWSNS AND UNDER WATER COMMUNICATION

6.1 Introduction

Several underwater acoustic modems are available as commercial products [36,37,38] and research platforms [39,40,41,42]. Underwater acoustic modems from LinkQuest are designed to address the three main obstacles in underwater communication; poor reliability, low data rate and high-power consumption. The company develops advanced underwater acoustic modems using proprietary Broadband Acoustic Spread Spectrum Technology from LinkQuest, with state-of - the-art technologies outlined below [36]:

- **a)** Advanced modulation scheme for enhanced signal to noise ratio
- **b)** Equalizing channels to combat multipaths
- **c)** Coding Error Correction
- **d)** Automatic rate change to combat varying noise conditions
- **e)** Most advanced hardware and software in DSP

6.2 Acoustic Modem Design

Throughout an underwater sensor network, the modem is responsible for implementing the physical layer of the network stack shown in Figure 10, just as in a terrestrial network. In other words, the modem is responsible for the actual physical transmission and data processing through the network. The MAC protocols (link), routing protocols (network), transport protocols (transport), and data processing (application) are responsible for the higher network layers [43].

Application
Transport
Network
Link
Physical

Figure 6. 1 The Underwater Acoustic Modem fits into the physical layer of a typical network stack.

Like in terrestrial networks, acoustics are used in underwater communications rather than radio frequency (RF) since it is a well-known fact that electromagnetic waves are increasingly attenuating underwater making them an inadequate carrier of data across water. Acoustic modems underwater consist of three main components, as shown in Figure 6.1. The front analog (dark grey), 2. Hardware (light gray) board, and 3. Serial (Black) Interfaces. The analog front end is responsible for translating electrical signals into sound waves and vice versa (transducer) and generating the correct level of power for the received and transmitted signals (analog electronics which include an amplifier [43].

The hardware device is responsible for monitoring and processing the signal i.e. performing modulation and demodulation using a particular signaling scheme (i.e. frequency shift keying (FSK), direct sequence spread spectrum (DSSS), or orthogonal frequency division multiplexing (OFDM), and performing error encoding and decoding. The serial interfaces are responsible for interacting with underwater sensors and/or network layers at higher rates. The designer needs to optimize implementation at every stage for a low-cost, low-energy acoustic modem system, from the analog electronics to the signal processing scheme, to the hardware platform. In this paper we focus on hardware platform design choice: digital signal processors, microcontrollers, or reconfigurable hardware, to optimize energy efficiency [43].

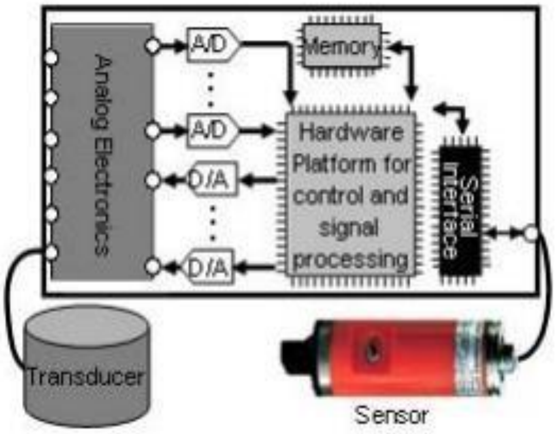

Figure 6. 2 Major components of an underwater acoustic modem: the analog front end (dark gray) the hardware platform (light gray) and serial interface (black)

6.3 Underwater Laser Communication

In [44], there is an experimental evaluation of the underwater laser communication. For testing underwater laser communication, a continuous wave laser operating at 532 nanometers wavelength was chosen. In coastal waters with high turbidity and high content of organic matter, the green light attenuation is less than that for blue laser light, making blue preferable for operations in clear water masses of the open ocean. Digital data from a notebook computer can be transferred via Ethernet to a modem of the transmitting unit of the underwater communication system. A converter drives an acoustic optical modulator (AOM), which is responsible for the intensity modulation of the laser beam. The system was designed for a data rate of 10 megabits per second.

The modulated laser light was transferred via a fiber optic cable to an underwater housing that contains a collimator. The transmitted laser beam passes a distance of three meters in the water column before it is coupled back into another fiber optic cable. With the help of a detector and a second modem, the optical signals are converted back to a digital data stream. The first tests were performed at WTD 71-FWG in 2009 in a basin and at a harbor mole. The water turbidity was chosen to comply with brown water conditions. After three meters of propagation, only 12 percent of the laser intensity remained. The path was further disturbed with injected air bubbles, which simulated breaking waves or the wake of a ship. As the laser beam diameter of 18 millimeters was large compared to the air bubble radius, damping by a factor of two was moderate compared to when no bubbles were present. In the basin and at the harbor mole, video streams and files were transferred with data rates between seven to 10 megabits per second. BERs remained less than 0.0001 percent. Allowing BERs up to 0.01 percent, the underwater laser could achieve a 10- to 20-meter propagation path under these conditions.

6.4 Underwater Laser Sensor Network

The most of the laser cannot enter the water because it is absorbed by the surface, but the blue-green laser (wave length is about 470~570 nm) has the lowest fading intensity in the sea, with a fading rate of about 0.155~0.5 dB / m. Hence, the blue-green laser will spread in the sea from several hundred meters to kilometers, and this feature of the blue-green laser at sea is said to be the windowing effect [45]. Some submarine communication systems based on the Blue- window effect have been developed. In these communications systems, the blue- is a collimated laser beam that should be focused on the submarine as sender attempts to communicate with the submarine. This is where we use the blue- as the new contact tool for an underwater sensor network.

Since the sensor nodes in the sea are still in the area, sensor nodes have trouble targeting one another. In comparison, we recommend not using the collimated laser beam, and we suggest using the diffused laser beam for underwater communication. For example, if the diffused angle is 30 °, a wide area would be covered by the diffused Laser beam. Even though the node which receives the sensor excurse a little distance, the contact signal can still be received. The process of sending and receiving is shown in Fig 6.3 [45]

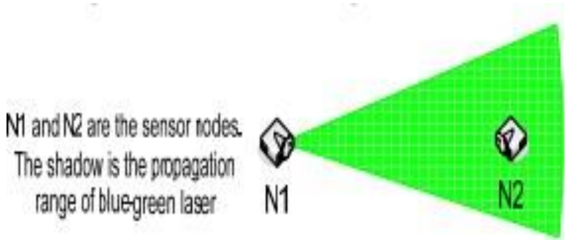

Figure 6. 3 The process of sending and receiving for the underwater blue-green laser sensor network

6.4.1 Underwater Laser Sensor Architecture

For comparison purposes, the underwater acoustic sensor network is used, and we then image the internal node structure in the underwater blue-green laser sensor network in Fig 6.4. It includes the sensor, the sensor interface circuitry, the memory, the power supply, the blue-green CPU and laser modem. The CPU gets the data into the sensor through the sensor interface circuit and then the CPU can store the data in the memory, process the data by itself and send / receive the data by controlling the blue-green laser modem [45].

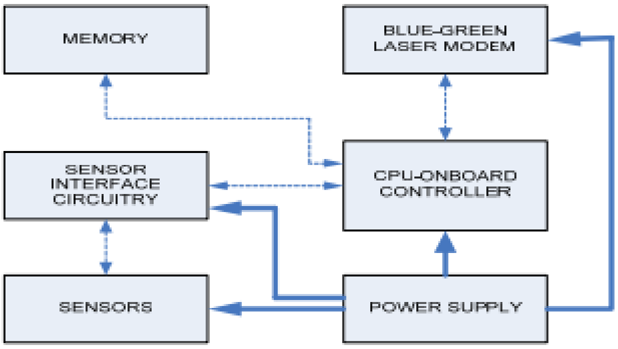

Figure 6. 4 Internal architecture of a node in the underwater blue-green laser sensor network

6.4.2 Protocol stack for the underwater laser sensor network

The protocol stack for the underwater laser sensor network will consist of physical layer, data connection layer, network layer, transport layer and application layer functionality. Given the vulnerable under water conditions, the underwater laser sensor network is distinct from the terrestrial sensor network. The energy management system, 3D topology management strategy, QoS management plane and mobile management are also included in the protocol stack. The underwater laser sensor network protocol stack architecture is shown in Figure 6.5 [45].

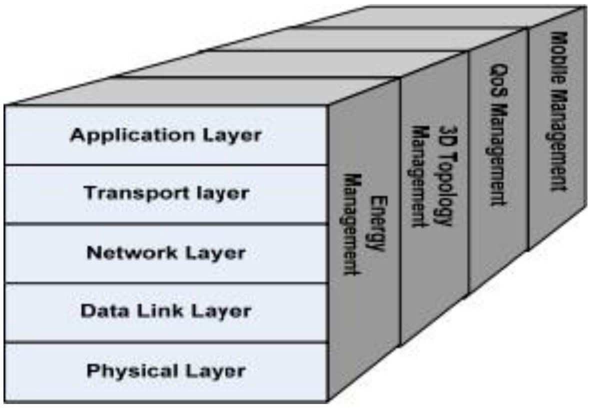

Figure 6. 5 The architecture of protocol stack for the underwater laser sensor network

The energy management plane in this architecture is responsible for the network functionality, with the goal of reducing energy consumption. 3D topology control plane is responsible for the control and adjustment of the underwater network topology according to the necessity of underwater exploration. The QoS management is responsible for the accuracy of data transmission and must ensure that the information transmitted is met for the application's requirement. Mobile management is responsible for sensor node movement, which will ensure the sensor node underwater is pushed equally. In other words, the sensor node must turn to solve the stream excursion automatically, and the sensor node will ensure that due to mobility, laser communication is not disreputable [45].

CHAPTER 7

OUR ANTICIPATED LEVERAGE ARCHITECTURE FOR UWSNS

7.1 Introduction

Underwater Remote Sensing through Free Space optics (FSO) is designed in line with the view of formulation of robust underwater sensor network architecture to cover a wide range of application of underwater sensor network. The architecture will be Fault tolerant, Low cost and will support High Bandwidth. The major component of the architecture is the node capable of communication through FSO. Analytical channel estimation will be performed for the FSO underwater which will be subsequently validated by the practical experiment. Effect of competent modulation scheme will also be analyzed and finally upper layer protocol suit will be developed.

7.2 Communication Architecture

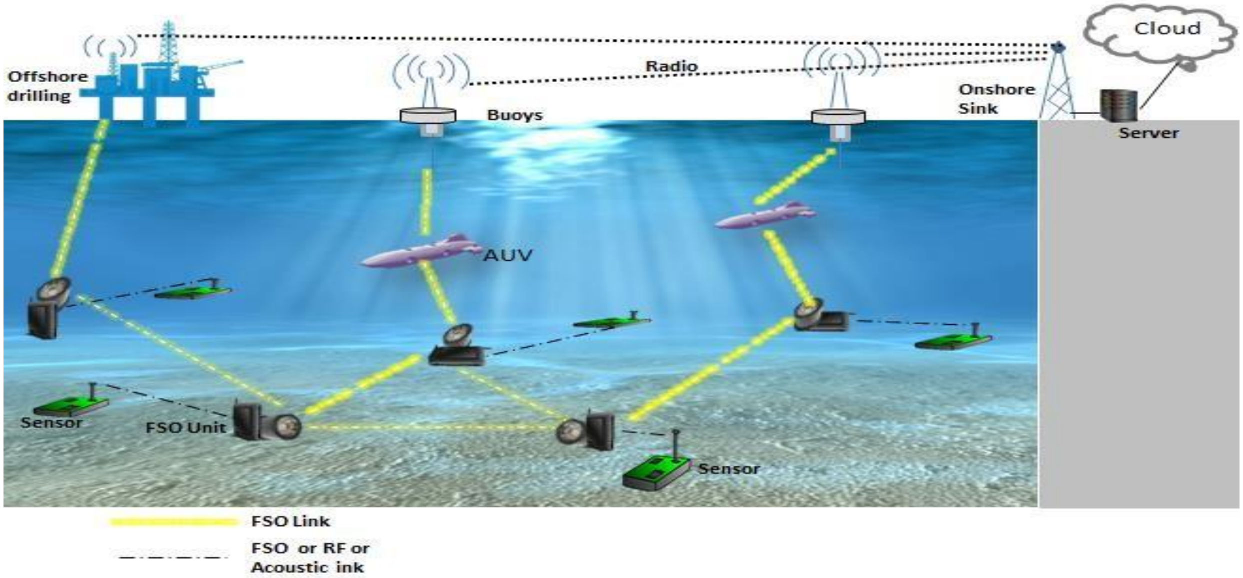

Figure 7. 1 High Level architecture of the Communication Network of the project

The high-level communication architectural view of the project is shown in Figure 7.2. As we see in the figure, there will be three main components underwater**.**

a) The sensor nodes are anchored with the ground. They can transmit of receive signal from the FSO unit which will work as a cluster head.

b) The second one is the FSO unit which is an integrated architecture with modem, light source, photodiode, and (or) camera/ sensor. These works as a cluster head (CH) of the sensor network with extended functionalities. It can communicate with underwater vehicle (AUV) or Buoys (depending on distance) through laser. It is also capable to connect with the other sensor nodes through FSO (Laser/LED), And/or Radio Frequency/ Acoustic link. It will work as a gateway for the data collected by the sensor nodes, simultaneously its function can be extended to data and image collection by itself and share and aggregate with other cluster head.

c) The third component autonomous underwater vehicle (AUV) can communicate with the cluster head (CH) and the buoys through FSO. The Buoys at the end will communication with the offshore sink by radio signal and also can communicate with the automated underwater vehicle or Cluster head or FSO unit (depending on distance) by FSO.

From our detailed investigation we can say that when we combined both acoustic and optical communication, we can get the maximum outcome to create communication over underwater sensor network.

7.3 Design an Analytical Model for Physical Link of Underwater Wireless Optical Communication

Natural oceans are rich in dissolved and particulate matter, leading to a large range of conditions that an underwater communication system must satisfy. Optical properties of water can be classified into two groups: inherent property and apparent property. Inherent properties (scattering, absorption etc.) describe optical parameters which depend only on the composition and particulate substances present.

Apparent property (radiance, irradiance and reactance etc.) is a directional property. It depends on the medium and the geometric structure of illumination. Due to a series of factors (exponential factors), FSO communication channel modeling underwater is very challenging. However, constituent properties and optical properties are coupled, implying that optical constants can be deduced from the local water composition. Based on that several proposals are presented by the research community. However, most of the cases the models are not validated experimentally.

Our goal is to analyze the existing model and come up with a unique channel estimation model for underwater FSO. The analytical model that we will develop will be validated by the experiment.

7.4 Use different Modulation Technique and Evaluate BER for Varied Water Condition for FSO

Various modulation scheme particularly On-off keying (OOK), Frequency Shift Keying (FSK), Differential Phase Shift Keying (DPSK), and the Pulse Position Modulation (PPM) and their variants will be evaluated with experiment. Usability of other possible modulation technique will also be explored. The optical transmission system involves optical signal modulation, transmission, detection, and demodulation. The intensity of an optical source is modulated in FSO communication systems for transmitting signals over channels. Amplitude, frequency, phase, and polarization of the optical signal can be modulated. There are various types of modulation schemes suitable for FSO systems that have compared the average optical power obtained needed to achieve the desired BER at the specified data rate.

A power-efficient modulation scheme for optimizing the ratio of peak to average power is desirable. The simplest and most commonly used modulation scheme in free space optics is intensity modulation with direct detection. The modulation scheme should be chosen based upon power efficiency, bandwidth efficiency, simple design requirement, low cost implementation and immune to interference background radiations. OOK is very simple in implementing and efficient in bandwidth between the different IM schemes. This modulation scheme includes adaptive threshold for better performance under turbulent atmospheric conditions. Using this scheme, the light source is switched on to transmit a "one" logic and shut off to transmit "zero" logic. It is also known as the modulation of the nonreturn to zero (NRZ). In addition to NRZ, the return to zero (RZ) coding can also be used in which the "one" logic in the center of the sample returns to null. RZ demonstrates greater sensitivity than NRZ [46].

OOK is influenced by the distortion of amplitude, i.e. fading and signal propagation through the various roots. When sky is clear these issues are least important. Coherent modulation schemes such as binary phase shift keying (BPSK) and differential phase shift keying (DPSK) can also be used in addition to the schemes described above. The BER efficiency of subcarrier BPSK is also higher than that of OOK under all the turbulence conditions. The coherent receivers are one to two times more reactive than OOK systems but, then, the complexity of the coherent system is also greater. OOK are better than coherent structures. The BER efficiency of subcarrier BPSK is also higher than that of OOK under all the turbulence conditions. The coherent receivers are one to two times more reactive than OOK systems but, then, the complexity of the coherent system is also greater. OOK are better than coherent structures. OOK systems were therefore preferred within the environment for optical connections. Pulse Position (PPM) modulation scheme is a method of orthogonal modulation [46].

PPM involves synchronization of both the slot and the symbols. Pulse position modulation (PPM) provides greater resilience to turbulence due to the availability of soft demodulation algorithms, where information is encoded in the position of the optical pulse rather than amplitude. The technique can boost OOK's power efficiency but at the cost of an increased requirement for bandwidth and greater complexity. For optimum detection it doesn't need dynamic thresholding. Subcarrier strength modulation schemes (SIM) modulate the RF carrier frequency and phase. The phase fluctuation in turbulent atmosphere is less pronounced, and thus SIM gives better output over OOK. The Differential Pulse Position modulation (DPPM) scheme is an improved version of PPM with enhanced throughput or bandwidth efficiency. The empty slots after a pulse in a PPM symbol are removed which improves the system's spectral efficiency [46].

In DPIM, the information is defined by the number of empty slots between pulses, potentially allowing higher data rates and power efficiency improvements as opposed to OOK and PPM. Dual-header pulse interval modulation (DH-PIM), which is a variant on PIM, reduces the number of' empty' spaces, and hence the length of the symbol, by adding a second pulse at the beginning of the text. DAPPM is a combination of PAM and DPPM, multiple pulse amplitude, and position modulation to increase the data efficiency, bandwidth capacity, and peak-to-average power ratio. Through DAPPM the symbol length and amplitude of the pulse are modulated according to the bit stream of input data. A summary of the literature related to Features Comparison of different modulation schemes is presented in table I and schematic waveform comparison for modulation schemes is shown in figure7.3 [46].

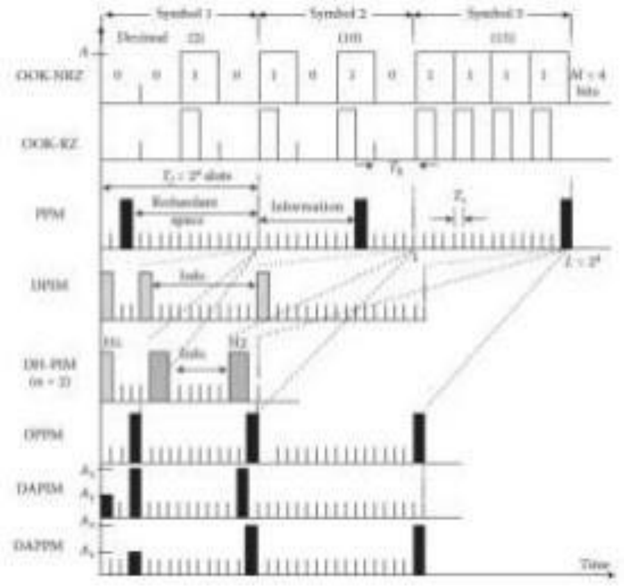

Figure 7. 2 Waveforms for OOK, PPM, DPI, DH-PIM, DPPM, DAPPM signals

7.5 MAC Layer protocol

There are many proposals for the design of protocols for WSNs. In [47]-[48], detail elaboration of several MAC protocols for WSNs are compiled with few new proposals. In [49]-[50], novel idea about the energy efficient protocols and protocols with QoS are presented by the authors. In [51]-[60], authors mainly focus on the cross-layer protocol for WSNs. Though there are many proposals for WSNs but compared to that very few researches have been conducted on UWSNs. Recent call on marine biodiversity discovery techniques, environmental monitoring programs and disaster resiliency agenda demand for technologies and researches on underwater monitoring. In this light, Underwater Sensor Network (UWSN) has been one active area in the field of wireless sensor network (WSN). But due to the nature of this type of network, challenges have been encountered, uncovering the behavior and characteristics of underwater network [61].

Medium Access Control (MAC) layer protocol is important for any communication network. It is in the MAC layer protocol that nodes simultaneously access the transmission link, and thus part of their role is to resolve any collision between nodes. With this function, MAC layer protocols allow the huge number of sensor nodes to share the limited channel resource efficiently while maximizing its lifetime and overcoming channel challenges. Shared medium access protocols are categorized into contention-based, contention- free and hybrid MAC protocols. The contention-based protocols use randomization for shared access, while the contention-free protocols have schedules that control the node may use any resource at the time. The Hybrid MAC protocols considered the synthesis of both the contention- based and the contention-free advantages [61].

We will design implement a media access control protocol that allows multiple motes and neighboring cluster heads to communicate each other in a directional manner. The possible scheduling technique and synchronized process will be exploited to find an optimum MAC protocol tailored to our proposed underwater FSO sensor network. Both scheduled access (TDMA) and random access (CSMA) and their variants will be studied in order to find an optimum solution. It can be noted here that the efficacy of MAC protocol is very significant for achieving power efficiency which is critical for the case of underwater sensor deployment. After developing and testing with experimental setup; we will embed it with the FSO unit (cluster head) and FSO sensor node.

CHAPTER 8

APPLICATIONS AND CHALLENGES OF UNDERWATER SENSOR NETWORK

8.1 Applications of UWSNS

Wide usages of underwater sensor networks have made them one of the most promising technologies of today's era. Some of them are discussed as below [62]:

a) Oceanographic data collection:

When deployed, marine sensor networks give the on-shore oceanographers great advantage. Using sensor-gathered data, oceanographers help us gain a deeper understanding of how our oceans and living creatures' function as an ecosystem within them.

b) Underwater Pollution monitoring:

Sensors can be specifically positioned to detect underwater contamination caused by chemical, biological, or nuclear attacks. For instance, if oil is spilled then it can lead to water pollution. Therefore, we calculate the volume of emissions by using these networks.

c) Disaster prevention:

Sensor networks can provide tsunami alerts and detect seismic waves or activities across remote locations.

d) Discovering undersea resources:

We know oceans in themselves are a great secret. It is not easy for scientists to use manual power for underwater research and many observations can be made by deploying marine networks.

e) Equipment monitoring:

Equipment that is installed for a long time may be tracked using pre-installed software, but first installed equipment needs temporary and continuous monitoring to confirm successful installation during initial service or when issues are identified. Hence, using and deploying such network monitoring can be easily done.

f) Target detection and tracking:

Locating and hitting is a combined operation. Our basic objective under this operation is to detect a target, report it to the control station and then monitor its movements in trajectory. For example, if marine biologists want to monitor and record what particular species of fish eat in a certain region of the ocean, it may be smarter to deploy relatively low-cost sensor nodes to capture data in the area of interest, rather than deploy a team of scientists to collect the same data. Deploying sensor nodes can be less risky and more cost-effective than staying on a boat in the middle of the ocean for a certain amount of time.

The procedure for this activity can be explained as below [62]:

a) Determine the target's characteristics.

b) Choose right sensor type on the basis of characteristics among passive or active.

c) The sensors should be preloaded with information about the target.

d) Sensors should be capable of distinguishing between the target of interest and any other frequency which they can detect.

e) It will test the noise reading or measure background noise, also known as ambient noise, immediately after sensor placement. Ambient noise reflects the minimum noise level.

f) After this, all the noise received will be compared to the ambient noise and pre-recorded data.

g) Not every sensor will send everything to the base station, because it will waste a great deal of time and power. The data will only be transmitted when the obtained frequency matches the target's characteristics.

h) A large concentration should be dedicated to node location and distance so that the sensors are not positioned too far where the likelihood of detection decreases or they should not be placed near to the protected area.

i) Determine the topology of sensor networks that is based on goal after node placement. When the target moves, the topology is perpendicular to the sensors set, then it is a grid if it is stationary.

j) The network is built in the form of clusters where each cluster has cluster heads that transfer or function locally and cluster heads community operate globally.

k) The heads of clusters are responsible for monitoring targets that travel through their respective clusters. The data is redirected from the sensors to the head of the cluster.

l) The nodes route data to the current manager node which processes the data to track the target as the target moves through the sensor field.

Target detection starts when a target matching frequency is detected, and the nodes will have to analyze this information to determine a degree of trust that the target of interest is the frequency. If the frequency matches to goal, the data will be transferred to the cluster head that will process it and match any other indications. Nevertheless, if the manager node has no confirmation then it sends a warning message to other nodes in the vicinity.

When the target is identified by other nodes, then transfer information to the manager node that will locate it and send messages to other manager nodes in the direction of the target that warns their respective clusters if they are asleep to save energy.

The basic idea used for target detection is based upon Doppler's equation:

$$\boldsymbol{F_0} = \frac{(C + V_0)}{(\boldsymbol{C} + \boldsymbol{V_s}\ )} \times \boldsymbol{F_s}$$

Where:

F_0 = frequency observed by listener

C = speed of wave

V_0 =velocity of listener

V_s =velocity of source

F_s = frequency emitted by source

The basic principle of this algorithm is related to the sensor being able to detect any acoustic frequency. Let assume there is a sensor S that detects an acoustic frequency $F0$ emitted by a target source Fs and then calculate the frequency Vs. After calculating Vs, we derive two conclusions:

a) If ($F_0 > F_s$) then, the target is moving towards sensor.

b) If ($F_0 < F_s$) then, the target is moving away from sensor.

8.2 Challenges of UWSNS

Though from the above sections we learnt about the increasing prosperity of UWSN’s, however, still they suffer from various limitations as stated below [62]:

a) Cost:

Marine Sensors are very costly, and depending on the application, the sensor network requirement can be growing. Every sensor's cost should be kept low otherwise the sensor network is not cost-justified.

b) No real time monitoring:

The data recorded inside these sensors can only be available when the sensor is recovered which is not possible for the sensors deployed underwater in routine fashion. This is especially important in areas such as seismic surveillance.

c) Failures due to corrosion:

Marine Sensor nodes are deployed in very harsh environments like battlefields underwater, bottom of the ocean, moving ships etc. They are susceptible to failures due to corrosion and fouling. When errors occur, these cannot be detectable until the instruments are retrieved. It can trigger an entire monitoring mission to fail.

d) Limited storage capacity:

The sensors are limited in memory. Therefore, these can only store small quantities of data during the monitoring.

e) Low battery life:

Sensors have a restricted battery which is one of their limiting problems. A considerable amount of work is being done on this issue but there is still no solution to it. In order to preserve the battery, sensor enters sleep mode when not in use and a synchronization is given when any task or signal arrives to wake up. A sensor's battery life is a big problem, as charging them is very tuff.

f) Attenuation:

This means power loss. There may be diverse causes of water attenuation. Absorptive losses are often caused by a transmission media. The loss is mostly due to the refraction, reflection, and dispersal phase. There are also losses caused by surface reflections of multipaths, barriers, the water changes in the bottom and temperature.

CHAPTER 9

CONCLUSION

9.1 Summary

Our research work has summarized ongoing research in underwater wireless sensor network.

- **a)** Almost all the papers have highlighted the need for new underwater communications technologies since the spectrum of applications in the underwater environment is increasing rapidly.
- **b)** Many researchers have highlighted the difficulties and pitfalls in implementing new technologies in this area of study.
- **c)** The problems that should be addressed in sensing systems differ depending on the size of the region to be monitored. One or a few independent sensors may be used to track a small zone or a sensor network to track wide areas.
- **d)** Including video cameras and increasing the number of sensors inside the water has underlined the need for higher bandwidth to send more data in the wireless channels.
- **e)** Although underwater wireless sensor networks have been a popular issue since several years ago, it seems that this area will continue to be a popular issue for many more years to come due to the need for more technology in this field.

9.2 Scope for Future Work

In this thesis we discussed multiple aspects of underwater wireless sensor networks. We have also identified possible directions which are not yet discussed in this field of study. When considering the environmental impact during contact, a better communication strategy can be suggested. Concerning the life and contact of marine species, utmost care must be taken in the development of underwater communication technique. Spectrum sensing, dynamic power management, spectrum sensing policy, spectrum sharing and spectrum decision are major challenges for the design of the cognitive acoustic network. For underwater sensor networks a GPS such as localization sachem is not yet developed and the location of a freely moving node is still an open field for study. Besides this, the variable length packet can be further explored in communication.

9.3 Our Future Interest

For more than 70 percent of our world covered by water underwater research is needed for the next generation of science and industry. Underwater data is therefore difficult to obtain. The successful deployment of wireless sensor networks on the ground has led to their deployment underwater. In our whole investigation we mainly discussed various sectors of underwater wireless sensor networks. In the future, we will create a test bed that will assist us in establishing the network through the use of sensors in underwater [63].

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