Marine Information Technology Curriculum Report

Title： Underwater Wireless Communication and Current Emerging Technologies

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Major：Marine Science

Declaration

I declare that the assignment here submitted is original except for source material explicitly acknowledged, and that the same or related material has not been previously submitted for another course. I also acknowledge that I am aware of University policy and regulations on honesty in academic work, and of the disciplinary guidelines and procedures applicable to breaches of such policy and regulations.

Signature: Usman Dawood Butt

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CURRICULUM REPORT

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Introduction

Our earth the only planet where almost 75% of its surface is occupied by oceans and these oceans are far-fetched and unexploited due to distinct activities underwater. Monitoring these activities such as environmental impact surveillance & marine life is essential. The ever expanding exploration of naturally occurring resources and the competition in the field of war strategies in recent times has sparked many technological advances in the field of atmospheric and military surveillance among others. In this regard, underwater wireless communication (UWC) has become a significant field. UWC has a vital contribution in monitoring of marine ecosystem, pollution status, oil and gas exploitation, disasters monitoring, tactical actions for coastal surveillance and to observe the fluctuations in marine environment. In this aspect, UWC has become a significant field of study for numerous defense and business applications with increasing interest to explore the underwater world. Optical, acoustic, RF and electromagnetic waves are the current emerging technologies for data transmission in UWC. For instance, Underwater Wireless Acoustic Communication (UWAC), Underwater Optical Wireless Communications (UOWC), Underwater Wireless RF Communication (UWRFC), Autonomous Underwater Vehicles (AUVs), Underwater Wireless Sensor Networks (UWSNs), Underwater Acoustic Networks (UANs), Underwater Electromagnetic Communication (UEC) and Underwater Wireless Communication Networks (UWCNs) are some examples of recent advancements. UWCNs and AUVs have been used for sharing data, interacting and coordinating with one another to carry out sensing and surveillance operations. All the above mentioned networks interact each other by using different nodes and land-based stations [1]. Nowadays, the use of internet of underwater things (IoUT) and 5th Generation (5G) networks emerged as supportive technologies for UWC by improvement of the data rate, energy efficiency and better connectivity [2]. Furthermore, the emergence of 5G network assisted UWC techniques are also under consideration by many researchers. These wireless communication technologies have also become part of our daily life. The most common example is mobile phones equipped with bluetooth, CDMA and 5G Network technologies.

Apart from the advantageous nature of current underwater wireless communication technologies there are some limitations as well that are attached with its use. For instance, the performance of UOWC is associated with the physical properties of the medium that restrict the bandwidth, generate high transmission loss, Doppler’s spread, produce high latency and varying with time multi-path propagation [3]. Moreover, ordinary acoustic underwater communication, because of its bad features such as high bit error rates, low bandwidth, large and variable propagation delays, are specifically at risk to malicious incursions [4]. To encounter above mentioned issues related to UWC, Visible-light communication (VLC) technology is recently introduced.

Problem Statement

Global warming evolved as a major issue in recent decades, due to the rapid climatic shifts. Eventually resulting in gradual melting of ice caps in polar regions and give rise to sea level. Therefore, observing environmental activities, collection of oceanographic data, water sampling and water pollution is of great necessity. In past few decades, study of changes in the global climate, the exploration and investigation of the unguided water environment became a major point of interest. The crucial discoveries of recent times, for example the discovery of Titanic wreck and the hydro-thermal vents, were made possible using cabled submersibles. But such systems are indispensable if high-speed communication link is to be made in between remote end and the surface, it is essential to think about accomplishing something cost efficient and with the use of heavy cables. Nowadays, sensor technology and vehicular technology together with UWC is being employed for field observations, gathering data and its analysis, deep sea navigation, disaster prevention and early detection warning systems [5]. UWCs are difficult to deploy, which is due to the channel characteristics such as the salt concentration of water, pressure in the underwater environment, temperature changes, light proportion, winds and underwater waves propagation [6]. Regardless of all challenges, UWCs beyond doubt plays significant part in deployed underwater applications, which has an influential impact on the wireless network.

Underwater Wireless Communication

UWC is an emerging technology for premier research in underwater environment. It is a comprehensive wireless technology having intelligent computing, smart sensing and communication abilities. Underwater Wireless Communication (UWC) has high stature in ocean data analysis, underwater observation, exploration and monitoring applications. However, due to complex nature of ocean water, several practical challenges exist in deployment of UWC links. Qualitative and effective research has been carried out by research fraternity in UWCs from last few decades. UWC is used to get early warnings of natural disaster like tsunami and can provide water level rising information in oceans. Recently there are three customized approaches which are being used for underwater wireless signal transmission. The first technology featuring high data rate over short ranges is Electromagnetic waves. Secondly the Optical signal transmission (OPT) technology is used to achieve high data rate and bandwidth over moderate distance. However, a line attenuating position is required for signal propagation in this technology. Acoustic wave is another most widely used technology for long range communications.

All the above mentioned technologies should consider low complexity, low implementation cost, error correction capability and low energy consumption. Implementation cost is related to system throughput for required communication range. One stringent design constraint is maximum transmission power required for this communication. Transmit power can lead environmental impacts such as interference. Reliability insurance and power optimization appears as an important concern while dealing with these underwater technologies pressure and density tend to rise while increasing depths in oceans. The upper layer is always denser than corresponding water layer. Due to physio-chemical properties of water channel, optical waves experience dispersion, refraction and reflection. In such conditions, RF antennas located at land stations and floating devices can be used to exchange data. It is also possible to deploy numerous stationary and mobile sensor nodes consisting of AUVs for communication in any underwater network.

It is possible to establish a software-defined network (SDN) in such flexible communication environment in which greater number of communication devices, with their inherent features, can make data exchanges. Taking this into account wireless links are most acceptable for underwater applications, proper knowledge of the constraints over the physical layer of information transmission must be acquired.

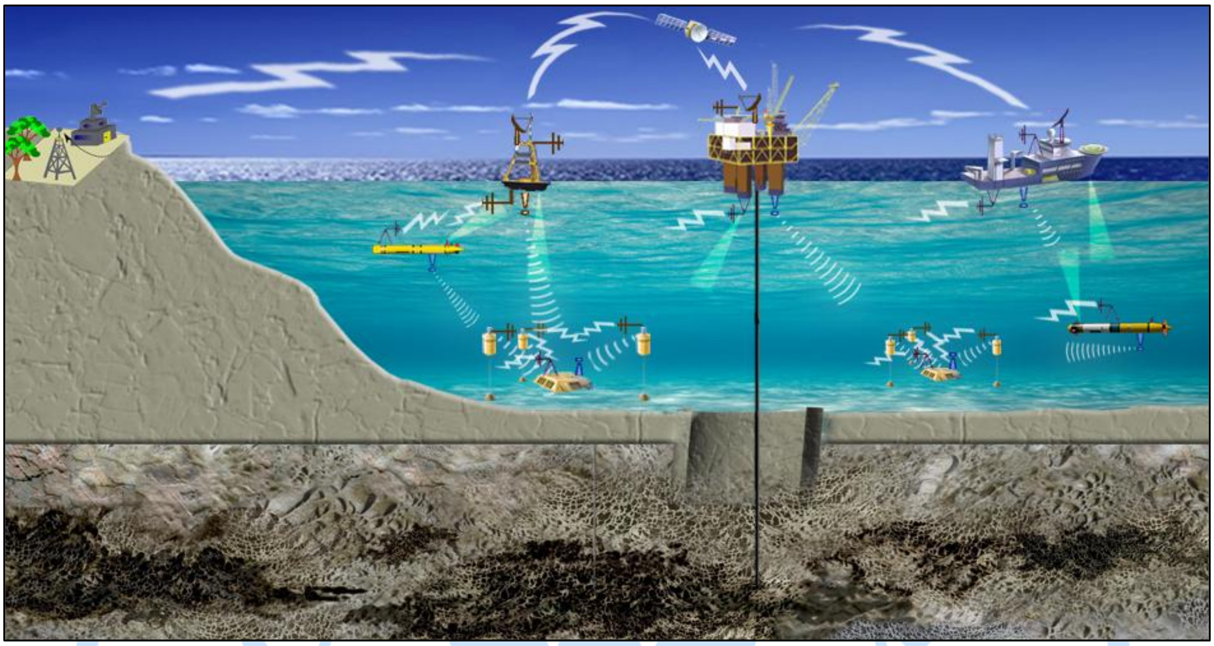


Figure 1 *Scenarios of multiple communication technologies [7].*

Underwater RF Communication

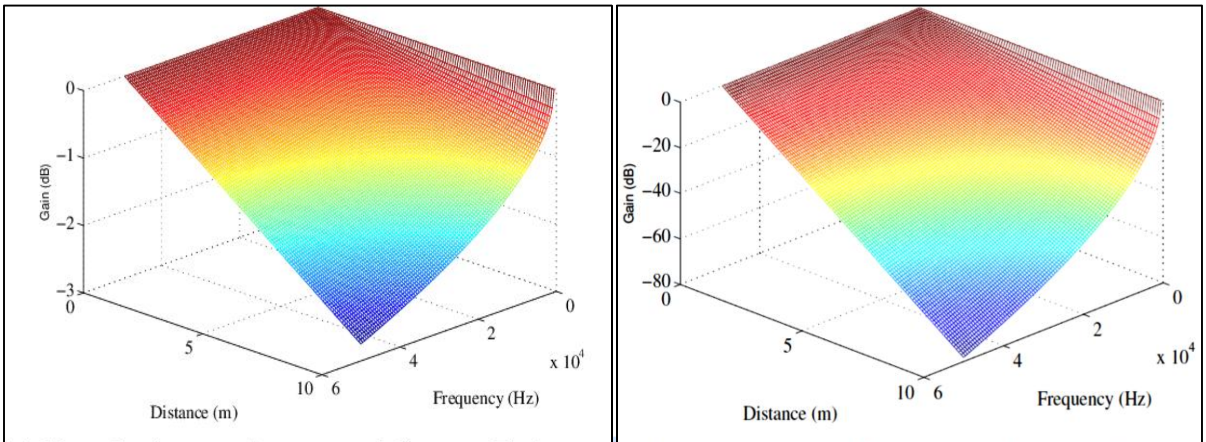
EM waves used for signal transmission between underwater and terrestrial communication platforms. EM waves covers few kHz to 1 GHz of frequency ranges. RF buoyant underwater communication systems used to deploy EM waves propagation setup for shallow water over tens of meter [8]. The possibility of RF signal propagation is on high in skin-deep water than greater depths. The oceanic water is more conductive which could seriously affect by propagation of electromagnetic wave. Thus, it is very less likely to establish long distance communication in the underwater environment, with very high and ultra-high frequency ranges (VHF and UHF). The electromagnetic waves attenuation considered to be lower enough over several kilometers in underwater environment to achieve expected communications [7]. Thus, the multiple-path propagation is an additional benefit for transmitting underwater signals in inland water reservoirs, i,e lakes, rivers, etc. from submerged communication nodes to onshore base stations. In UWRFC, signals experience high attenuation than in terrestrial communication.

RF signal propagation is environment dependent, such as frequency, salinity and temperature. The channel attenuation or absorption coefficient in per meter of ocean water can be expressed as:

$$\alpha(f) = \sqrt{\pi\sigma\mu_0 f}$$

Equation 1 *Absorption Coefficient in Seawater [9].*

where radio frequency denotes by f and σ represents the water conductivity. The permeability of the vacuum describes by $\mu_0 \equiv 4\pi 10^{-7}$ H/m. Whereas, value of μ_0 is almost equal in freshwater and seawater.



(a) Channel gain *versus* frequency and distance - Fresh water. (b) Channel gain *versus* frequency and distance - Seawater.

Figure 2 *Channel properties for RF Communications [7].*

Issues in Underwater RF Communication:

The unpredictable condition of ocean environment generates some serious challenges such as propagation loss in establishing RF communication link. Moreover, RF signals face detrimental issues of environmental noise and severe frequency selective channels. Channel capacity can be approached through reliable channel and noise estimation. Multicarrier transceiver can be opted as possible solutions with appropriate channel loading and state estimation. Hence, RF technologies possess rigorous constraints on propagation distances and data rates. There are the major drawbacks for smaller number of products using RF technologies. However, some alternative technologies based on optical and acoustic transmission are not feasible solutions. For example, sensor networks are deployed to monitor seabed sediments in order to control coastal erosion and these sensor networks can exchange data via RF signals [10].

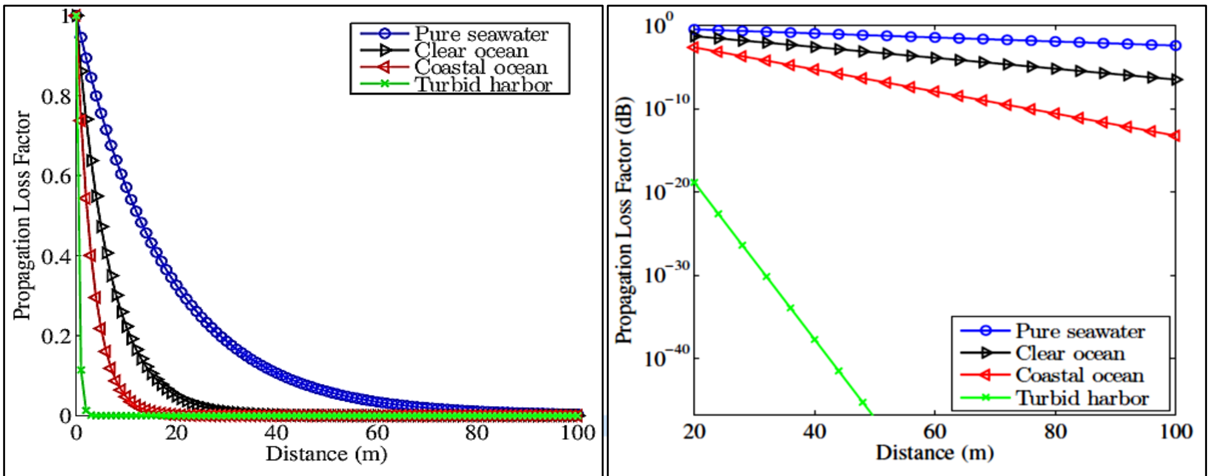
Underwater Optical Communication

Medium behavior is the main difference between RF and optical propagation in seawater: as water is a conductor for RF and dielectric for optical propagation. Plasma frequency explains this phenomena, whose value decide the range of frequencies for which the medium behaves as a conductor or as a dielectric. During propagation at different frequencies over different ranges UWOC has many distinct properties in different water mediums [11]. Propagation speed of acoustic waves in fluids might be four to five times lower in magnitude than the light speed. Optical communication is affected by dispersion, line of sight (LOS), temperature fluctuations, physiochemical properties of the water and by scattering. In dielectric medium, the possibility to achieve high data rates through UWOC technology as compared to UWRFC, in which propagation range is limited up to tens of meters [7]. In addition, the negotiation of Doppler effect can be obtained in optical communications as compare to competitive schemes, i.e., EM, acoustic. In UWOC propagation, the coefficient of beam attenuation has direct connections with the intensity and separation distance of light sources. Light intensity at receiver end can be expressed as:

$$I = I_0 exp^{-cd\lambda}$$

Equation 2 *Light Intensity at The Receiver [12].*

where I_0 and I are the intensities of light for both ends of transmitter and receiver, d represents distance in-between transmitter and receiver.



(a) Attenuation of the optical signal (propagation loss factor).

(b) Detail of the attenuation of the optical signal (propagation loss factor).

Figure 3 *Channel properties for Optical Communications [7].*

Issues in Underwater Optical Communication:

The two critical effects that disturb the propagation of optical waves in underwater are absorption and scattering. Phenomena of these two factors can be understood by the geometrical model of a water element ***(Figure 4)***. In case the input beam of the strength of light $P_i(\lambda)$, small fraction of incident beam $P_a(\lambda)$ absorbed and fraction $P_s(\lambda)$ scattered by water element. The unaffected result $P_c(\lambda)$ moving through water element with volume V and thickness r respectively. The absorption and scattering phenomena on the basis of energy conservation balancing can be expressed by the following equation:

$$Pi(\lambda) = Pa(\lambda) + Ps(\lambda) + Pc(\lambda)$$

Equation 3 *Absorption of Scattering [8].*

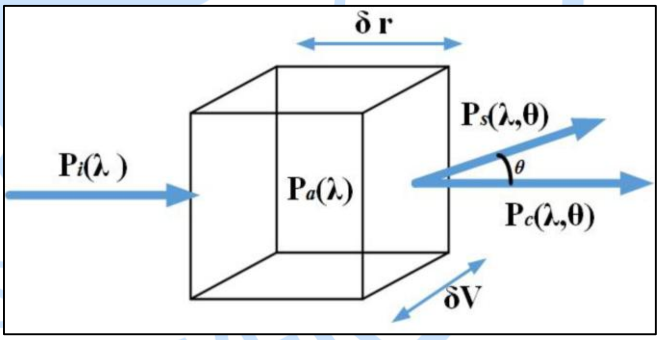


Figure 4 *Optical wave scattering and absorption underwater [2].*

Underwater Acoustic Communication

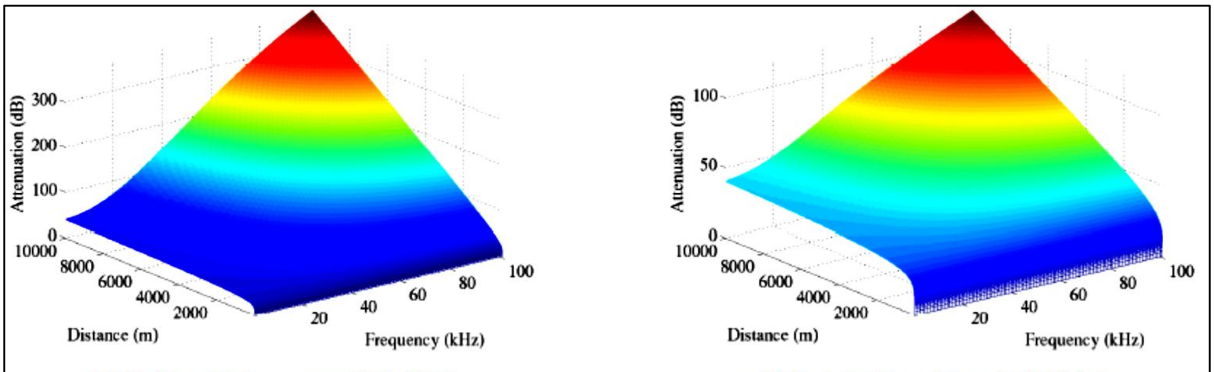
Both RF and optical transmissions possess bounded propagation range. The former can lead to a small propagation distance due to severe effect of strong attenuation, whereas the latter depends on the turbidity. Thus, as an alternative technology emerged acoustic communication that is currently being the dominant technology for UWC because in can reach higher distances.

Waveform's propagation speed relies on the mechanical or electromagnetic features of the medium. EM waves can pass through air at almost the speed of light in vacuum, around 4 to 5 orders of magnitude larger than propagation speed c of fluids in acoustic waves resulting in immense constraints on the total transmission process using acoustic waves. Indeed, in acoustic-based communications the parameters affecting the speed of propagation play a major role. Up to 1000 meters depth (in meters per second) model for the sound speed profile (SSP) for underwater environments is:

$$c = 1449.2 + 4.6T - 0.055T^2 + 0.00029T^3 + (1.34 - 0.01T)(S - 35) + 0.016z$$

Equation 4 *Model for the Sound Speed Profile [12].*

where T is temperature (in °C), S represents salinity (in parts per thousand), whereas, z is the depth of water (in meters).



(a) Shallow water — ocean depth 60 m. (b) Deep water — ocean depth 10 km.

Figure 5 *Channel property for acoustic communication [7].*

Common Issues in Underwater Acoustic Propagation:

The main issues in underwater acoustic propagation that affect communication links through man-made noises, high and variable propagation delay, path and multi-path losses and Doppler spread. The following factors are effective issues on acoustic communication.

- Losses: The main factors such as propagation signal energy losses, absorption and scattering loss respectively.
- Man-made and ambient noise: Ambient noise related to hydrodynamics of water such as an underwater thunderstorm, water movement, water tides, bubbles and fain, wind, rain and biological phenomena. The ambient noise losses up to 26 dB/km. Man-made noises produced by machine tools such as pumps, power plants, submarines and ships etc.
- Attenuation: Attenuation occurs by absorption of the acoustic energy that transforms into heat, scattering, refraction reverberation phenomenon, and dispersion. Attenuation of acoustic waves is directly proportional to the frequency of waves and depth of water medium.
- Absorption: The energy conversion phenomena of acoustic waves in another form of energy by chemical characteristics of the water channel.
- Geometric expansion: Geometric expansion is a spreading experience and function of energy loss in acoustic waves over the large area. When the acoustic pulse propagates from source of origin and covers a large water area, the wave energy per unit area become smaller.
- Path and multi-path propagation losses produced by the degradation of acoustic waves and generates Inter-Symbol Interference. The multi-path propagation are the geometrical constraints and configuration link dependent. In Vertical channels develops a little time dispersion but through water layers, it has a long multi-path spread, which is depends on water depth.
- Doppler frequency spread is an important factor in UWAC, due to a low diminishing performance of transmission and digital communication at high data rate [11].

Parameter	Acoustic	RF	OPTICAL
Attenuation	Distance and frequency dependent (0.1–4 dB/km)	Frequency and conductivity dependent (3.5–5 dB/m)	0.39 dB/m (ocean) 11 dB/m (turbid)
Speed	1500 ms^{-1}	2.3 x 10^8 ms^{-1}	2.3 x 10^8 ms^{-1}
Data Rate	Kbps	Mbps	Gbps
Latency	High	Moderate	Low
Distance	More than 100 km	≤ 10	10 – 150 m (500 m potential)
Bandwidth	1 kHz – 100 kHz	MHz	150 MHz
Frequency Band	10 – 15 kHz	30 – 300 MHz	5 x 10^{14} Hz
Transmission Power	10 W	mW – W	mW – W

Table 1 *Comparison of UWC Technologies [13].*

Emerging Underwater Communication Technologies

5G Integration in Underwater Communication:

Among other networking technique in wireless communications 5G wireless network is also emerged with extremely low latency and high data rate. Generalized frequency division multiplexing (GFDM) and Filter bank multicarrier (FBMC) are the latest promising techniques for 5G applications in underwater environment. GFDM is a multicarrier scheme that based on time and frequency, which is derived from filter bank approach. FBMC also addresses both time and frequency dispersions that should be constructed by using prototype filter [2].

Energy Harvesting:

It is a new approach for capturing and transforming usefulness energy to usable electric power in which energy requires in terms of RF signals, heat and vibration. For instance, wireless power transmission (WPT) technique is promising example of EH technique.

Massive multi-input-multi-output (MIMO):

MIMO supports underwater acoustic communication through hydrophones array as well as various kinds of multimedia communication contents in real time activities and visual conferencing. Moreover, it may improve throughput, capacity and energy efficiency of UWC system in the near future.

mmWaves enabling Underwater Communication:

Due to high demand of improving communication networking capacity, mmWaves are an alternative solution to support underwater communication and provide comparable characteristics to optical wireless signals. Thus these waves are considered to offer high efficiency and bandwidth transmission to improve the performance. The waves are a possible solution of hybrid communication because of up to 10 gbps data rates.

Non-Orthogonal Multiple Access (NOMA) as wireless carrier:

NOMA presents worthwhile communication benefits and a good technique of multiple access. As it minimizes the delay and allows to connect multiple users simultaneously. NOMA also provides allocation schemes in Underwater acoustic networks architecture and equal transmission times power allocation and capable to prevent the wasteful resources generation in underwater environment, proposed for future perspectives.

Internet of Underwater Things (IoUTs):
It is an emerging technology that enables devices to connect wirelessly. The integration of IoUTs plays a vital role to allow data sharing between UWSNs and the underwater base station. It also provides a great deal for observing and understanding marine life and their underwater habitats.

Underwater Wireless Communication Networks (UWCNs)
UWCNs are composed of AUVs having sensors to interact, coordinate and share data with one another to accomplish sensing and monitoring operations.

Attacks on UWCNs
UWCNs are specifically vulnerable to malicious attacks because of high bit error rates, low bandwidth of acoustic channels, large and variable propagation delays. Each sensor-AUV and intervehicle communications can be interfered by denial-of-service (DoS) attacks. Following are the possible list of attacks:

Jamming Attack:
Interfering with the physical channel by putting up carriers on the neighboring frequency nodes use to communicate in known as jamming attack. As the bands of acoustic frequency are narrow, increases the vulnerability of UWCNs due to narrowband jamming. Replay attack affects the localization as attacker jams the communication between a sender and a receiver, and replays the same message with stale information instead (an incorrect reference) pretending as the same sender.

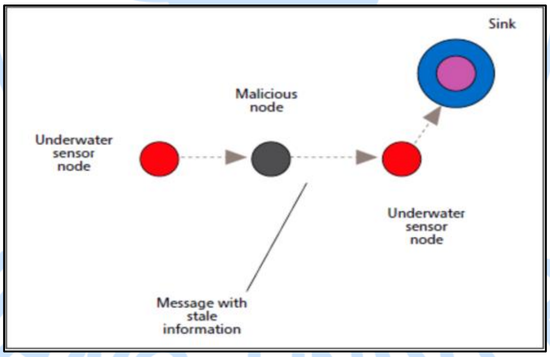


Figure 6 *Replay Attack [4].*

Wormhole Attack:
It is kind of an out-of-band connection generated by the attacker in between two different physical locations in a same network with lower delay and high bandwidth rate than normal connections. Such connections imply fast radio or cabled links to notably minimize the propagation delay. Furthermore, in such attacks some selected packets are transferred by malicious node reaches at one end of the wormhole to the other using the out-of-band connection, and re-infiltrate them into the network. This creates false neighbor relationships, because two nodes out of each other's range can conclude that they are in range of one another due to the wormhole's influence. Moreover, the adversary can monitor network traffic and delay or drop packets sent through the wormhole because routing protocols choose routes that contain wormhole links because they appear to be shorter.

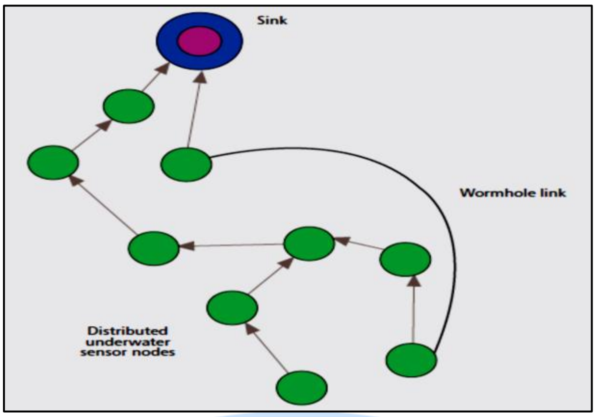


Figure 7 *Underwater network with a wormhole link [4].*

Sinkhole Attack:

Malicious node in such attacks attempts to attract traffic from a certain area toward itself. For instance, these malicious nodes can generate a high-quality route. Possible defenses to counter these attacks are geographic routing and authentication of nodes exchanging routing information, however geographic routing is currently a hot topic in UWCNs.

HELLO Packet or HELLO Flood Attack:

A malicious node received by the actual node as a HELLO packet may interpret that the adversary is a neighbor; this assumption will be considered as false in case the adversary uses high energy for transmission. Although the accuracy is not good due to node mobility and the high propagation delays of UWCNs but bidirectional link verification can still protect against this attack. Authentication is another possible way.

Acknowledge Spoofing:

Spoofing of link layer acknowledgments with the objective of reinforcing a weak link or a link located in a shadow zone can be done using the information sent to neighbor's node as a malicious node overhearing packet. These shadow zones are formed by the bending of acoustic rays blocking the penetration of sound waves. Further causing loss of connectivity and high bit error rates thus manipulating the routing scheme. Encryption of all packets sent through the network is a possible solution to this attack.

Selective Forwarding:

Instead of forwarding certain messages to hinder routing malicious nodes drop them. However, the verification should be done to check whether the lack in receiving information is due to the attack or because of receiver's location in a shadow zone. Fortunately, we can counter this attack by multipath routing and authentication, however, the communication overhead will be increased in multipath routing.

Multiple Identity or Sybil Attack:

Attacker can certainly pretend to be in many different locations at once with multiple identities. Adversary with multiple identities can also claim to be in several locations at once to misled geographic routing protocols. Although position verification in UWCNs is problematic due to mobility but still this attack can be prevented through proper authentication and position verification.

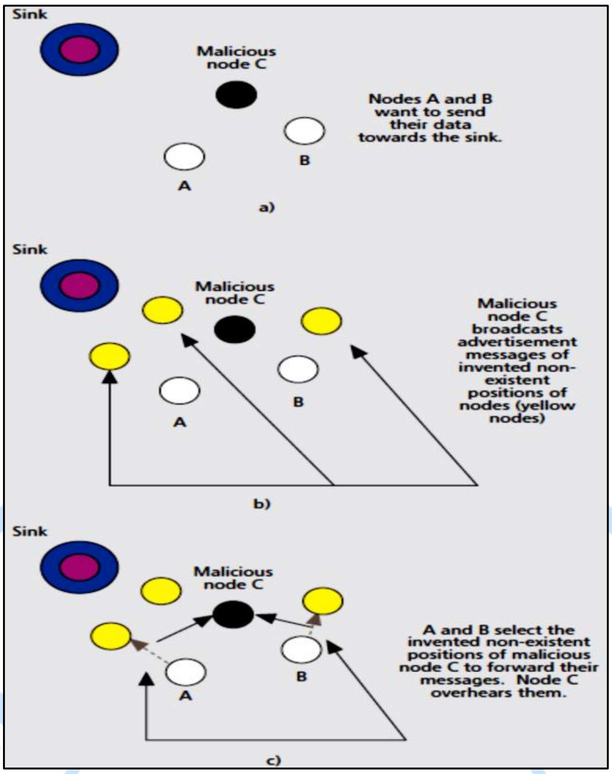


Figure 8 *Sybil Attack [4].*

Conclusion

The UWC technology allows a foundation for the creation of network connection between offshore based stations and underwater devices where the communication channels facing crucial environmental challenges. Discussed technologies and the solutions for related problems is to get the better understanding of the mode of deployment of underwater wireless acoustic, electromagnetic and underwater optical wireless communication technologies. The proposed technique of 5G wireless networking to support acoustic, optical and RF signal carrier is essential for the betterment of communication possibilities. As per the requirement of relevant communication technologies, a channel modeling to setup conceiving communication to ductile or firm network nodes are quite testing. The main outline of this report is new advanced communication techniques, technical issues and challenges in underwater networks and communication of entire technologies towards the next generation wireless networking system.

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