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A Survey of Acoustic Underwater Communications and Ways of Mitigating Security Challenges

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ABSTRACT*: Underwater Communication Networks (UWCNs) has become in the recent decades, a technology of utmost importance especially in the oil industry, defense industry and search and rescue operations. Underwater communications face some of the most unique challenges, first and foremost is the high attenuation that occurs in an underwater environment along with high bit error rates, large and variable propagation delays, and low bandwidth of acoustic channels. And Because of the aforementioned reasons, underwater communications are also prone to malicious attacks. In this paper, we look at underwater wireless communication and perform a survey of security and robustness for UWCNs and the research challenges for secure communication. Solutions investigated include choosing the best carrier frequency to minimize transmission losses, choosing the best modulation technique and proper design of the receiver.*

Keywords:– *Underwater Communication, Wireless, Security, Propagation*

I. INTRODUCTION

Underwater wireless communication refers to techniques of transmitting and receiving information underwater using wireless means. Applications of underwater wireless communication include the oil industry, military and environmental operations. Different techniques can be used to achieve underwater wireless communication. These include acoustic waves, radio frequency electromagnetic waves and optical wireless communication. Acoustic waves are the most popular, efficient and proven technique for achieving underwater wireless communications. Among the three, acoustics offer the longest range. It offers a range of up to 20 km [1-2]. RF electromagnetic waves suffer from having a limited range through water due to attenuation and are susceptible to electromagnetic interference [3]. The requirement for line of sight when using optical communications imposes a significant constraint on its under water application.

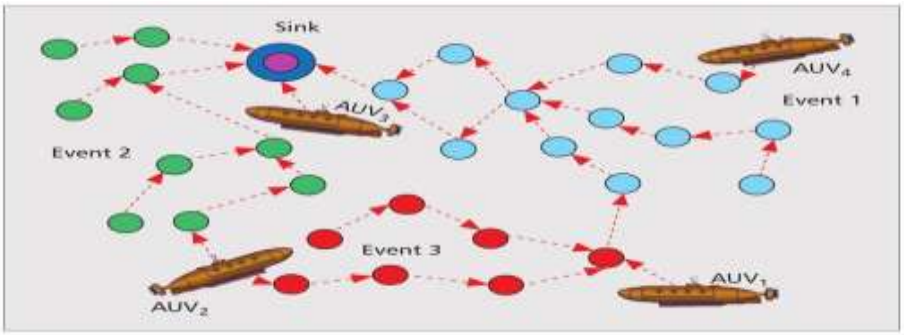


Figure 1 Underwater Sensor Networks with UAVs

Underwater wireless communication networks (UWCNs) consists of sensors and Autonomous Underwater Vehicles (AUVs) that interact to perform specific applications (Figure. 1). Security of Coordination and sharing of information between sensors and AUVs becomes challenging [4]. Reliable communication in

inter-vehicle and sensor-AUV is difficult due to the mobility of AUVs and the movement of sensors with water currents. This article discusses security in UWCNS. It is structured as follows. This paper outlines the characteristics of UWCNs in comparison with their ground-based counterparts. Also considered is, underwater wireless communication using acoustic waves. We discuss the characteristics of acoustic underwater and techniques used to overcome the challenges of underwater wireless communication. Subsequently, security requirements are described. Later, the challenges related to localization, secure time synchronization, and routing are discussed, and the best practices are proposed.

II. CHARACTERISTICS OF ACOUSTIC UNDERWATER WIRELESS COMMUNICATION

a. Challenges of underwater wireless communication

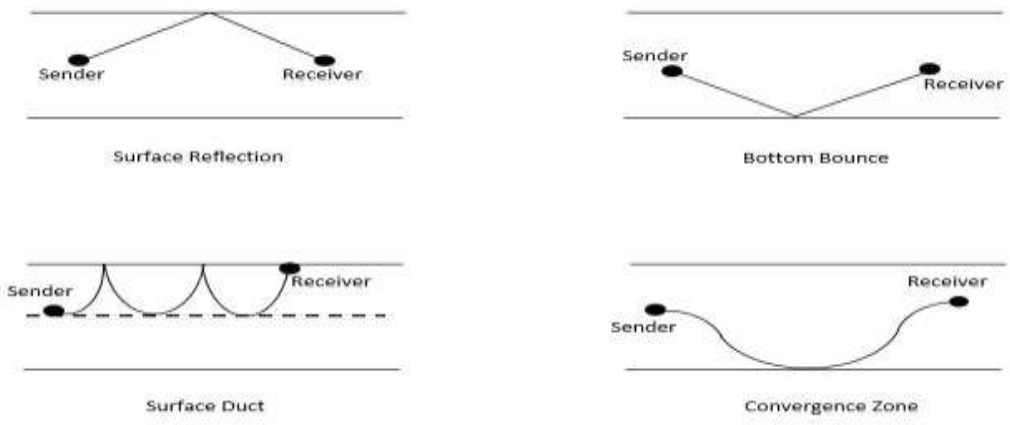
There are many different challenges that have to be overcome for underwater acoustic wireless communication to work. Low bandwidth, high attenuation, multipath propagation and huge propagation delay due to low speed of acoustic waves under water are the main limiting factors and challenges of acoustic communications. [5] The propagation delay is high because the speed of acoustic waves under water is 1500 m/s. The bandwidth available is only up to a maximum of 400 kHz, minimizing communication energy is also a concern because the communication instruments that are used for underwater communication are powered by batteries.

In order to overcome the challenges of underwater wireless communications, various design factors can be considered. In order to limit power consumption, the best carrier frequency has to be chosen. When designing the transceiver, the factors that have to be considered to achieve high bandwidth efficiency and low error rate include modulation, coding and error correction techniques.

b. Underwater signal propagation

Propagation of acoustic waves under water is affected by many factors. Acoustic waves propagating under water are subjected to refraction and reflection. Different water temperature, pressure due to depth, salinity and effect shadowing zones are factors that contribute to reflection and refraction of acoustic waves [6]. Due to refraction and reflection acoustic waves propagated through water will experience multipath propagation and fading.

Figure 2: Propagation paths between source and receiver in deep water [A3].



The factor that affects multipath propagation in the most significant manner is the depth of the wave under water. Other factors that affect multipath propagation, but to a smaller extent, are frequency and transmission range. Depending on the location of transmitter and receiver, multipath propagation can be affected

in different ways [7]-[10]. In deep water, there can be four propagation paths between the transmitter and receiver. As illustrated in Figure 2

Bottom bounce occurs when acoustic waves are reflected by the sea floor. Surface ducts arise if the surface layer is deep enough and has a positive gradient with respect to velocity resulting in bending of rays of acoustic waves towards the surface then reflection back into the layer. Convergence zones arise when acoustic waves from a shallow source are propagated into a deep sea. Acoustic waves in form of rays are bent downward as a result of decreasing temperature until the increase in pressure bends the rays upward.

III. CHARACTERISTICS AND VULNERABILITIES UWCNS

Underwater sensor networks have some similarities such as structure, function, computation and energy limitations with their ground-based counterparts. However, they also have differences, which, can be summarized as follows. Radio waves cannot propagate well underwater because of the high energy absorption of water, large propagation delays and low bandwidth The link quality of the underwater Communication is thoroughly affected by multipath, fading, and the refractive properties of the sound channel. As the underwater hardware is more expensive, underwater sensors are deployed sparsely. Acoustic communications are more power-hungry; also, typical transmission distances in UWCNs are greater; hence, requires higher transmission power to ensure coverage. [11-13] UWCNs have the following vulnerabilities. High bit error rate causes packet errors. Thereby, critical security packets will be lost. Wireless underwater channels will be eavesdropped on. Attackers may attempt to modify or drop packets. As power consumption in underwater communications is high, batteries of nodes pose a serious effect on the network lifetime. The UWCNS can be affected by denial-of-service (DoS) attacks. Next, we discuss typical DoS attacks and evaluate their dangers to indicate possible defenses to remove them.

a. Jamming

When a carrier is placed in the physical channel which interferes with the frequencies neighbor nodes to use to communicate, jamming attack is said to be occurred. As jamming is very common in wireless networks, few solutions proposed for traditional wireless networks Spread spectrum is the widely used defense against jamming.

This scheme is resistant to interference from the attackers, although not accurate, an attacker can interfere in a wide band of the spectrum or follow the precise hopping sequence. In a frequency hopping spread spectrum (FHSS) scheme. A high-power wideband jamming signal can be used to tamper direct sequence spread spectrum (DSSS) scheme. Underwater sensors under jamming attack should try to preserve their power. When jamming is continuous, sensors should be able to switch to sleep mode and wake up periodically to check if the attack is ended. When jamming is sporadic, sensors can buffer data packets and must only transmit high-power high priority information bits to report the attack as soon as a gap in jamming take place. Another generic solution proposed in ground-based sensor networks against jamming is to use alternative technologies fro communication such as infrared or optical. However, this solution fails, since optical and infrared waves are severely attenuated under water.

b. Wormhole Attack

Malicious nodes can create out-of-band connections via fast radio (above the water surface) and wired links, which are referred to as wormholes (Figure 3). Since sensors are mobile, their relative distances vary with time. The dynamic topology of the underwater sensor network not only felicitates the creation of the wormholes but it also complicates their detection. This attack is devastating. Routing protocols choose routes that contain wormholes links because they appear to be shorter; thus, the adversary can monitor network traffic and delay or

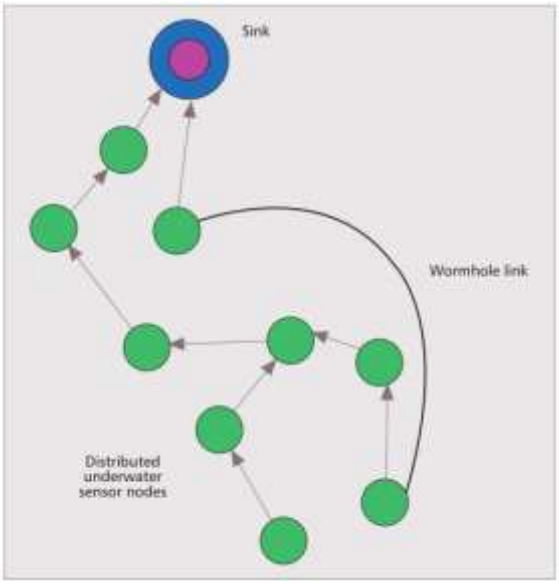


Figure 3. Underwater network with a wormhole link.

To detect a wormhole attack three-dimensional underwater distributed sensor mechanism is used. The approximated locational values, the angles at which the nodes are present and the lengths between them constitute to a virtual network topology. Any nodes found unfitting by these estimations are considered as a wormhole attack. This solution is possible on the direction of arrival (DoA) estimation of acoustic signals; therefore, it cannot be manipulated.

c. Sinkhole Attack

A malicious node tries to attract traffic from a particular area towards it. For example, the malicious node announces a high quality route. Geographic routing and authentication of nodes exchanging routing information are possible defenses against this attack.

d. HELLO Flood Attack

A node receiving a HELLO packet from a malicious node may interrupt that the opponent is a neighbor. This assumption is false when the adversary uses high power for transmission. Bidirectional link verification can help protect against this attack.

e. Selective Forwarding

Malicious nodes drop certain messaged instead of forwarding them to hinder routing. Multipath routing and authentication can be used to counter this attack.

f. Sybil Attack

A malicious node with many or multiple nodes pretend to be in many places at the same time. Geographic routing protocols are also misled because the adversary claims to be present at many places at once. Authentication and position verification are methods against the attack, although position verification is problematic due to mobility.

IV. TECHNIQUES USED TO OVERCOME CHALLENGES OF UNDERWATER WIRELESS COMMUNICATION

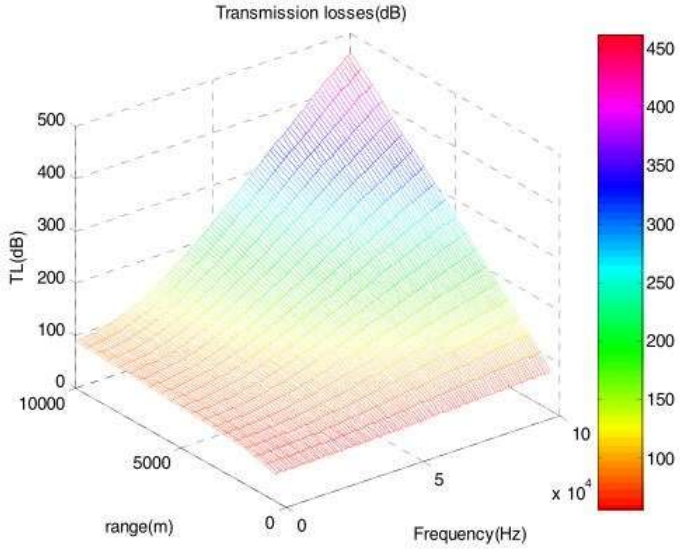


Figure 4 Attenuation vs Noise

a. Choosing the best carrier frequency to minimize path loss and noise

Acoustic signals travelling through water are distorted by factors such as absorption, Scattering and multipath fading. Multipath fading, absorption and scattering will all contribute to transmission loss when acoustic waves are propagated under water. The transmission loss will vary depending on the transmission range and the frequency of the signal. As the transmission range (distance between transmitter and receiver) and frequency increase, the transmission loss increases [14]. This is illustrated in the Figure. 4.

For example, for low frequencies of between 1 KHz to 20 KHz the path loss is not more than 50 dB for a, between 1 km to 5 km. Thepath loss does not go more than 100 dB for adistance of 10 km. In contrast, for high frequencies ofsuch as 50 KHz, the path loss is 200 dB for a distance of 10 km and more than 400 dB for a frequency of 100 KHz and same distance.

Since acoustic path loss is frequency-dependent, a greater bandwidth is available for shorter transmission distances while longer distances have a smaller bandwidth [15]. This is illustrated in table 1.

Table 1: Relationship between range and frequency

	Range[Km]	Bandwidth[KHz]
Very long	20≥	≤10
Long	5-20	5-10
Medium	1-5	≈20
Short	0.1-1	20-50
Very short	≤0.1	≥100

The relationship between signal to noise ratio, frequency and transmission loss for a narrowband acoustic signal with center frequency f(KHz) is given by:

$$SNR(d, f) = \frac{P/_{TL(d,f)}}{N(f)\Delta f} \quad (1)$$

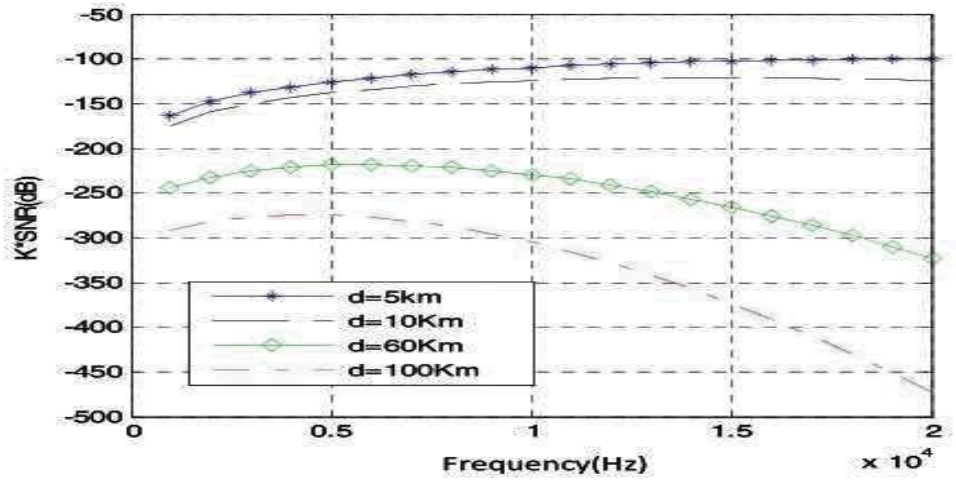


Figure 5: Frequency dependent part of SNR, 1/TL(d, f) N(f).

where Δf is the receiver noise bandwidth, P is the received power, d is the communication distance, and TL is the transmission loss. N(f) is the noise resulting from activity of ships, waves, turbulence and thermal noise.

Since noise and transmission loss are both dependent on frequency, there clearly exists an optimal frequency which minimizes noise. Choosing the optimal frequency which minimizes narrow-band SNR and as a consequence lower communication energy will be required [16] . This is illustrated in Figure .5 .

b. Modulation scheme and Bit Error Rate

The selected modulation scheme affects free bit error rate (BER) of underwater communication channel. Figure [6]shows that non-coherent frequency shift keying (16FSK) provides the largest range while

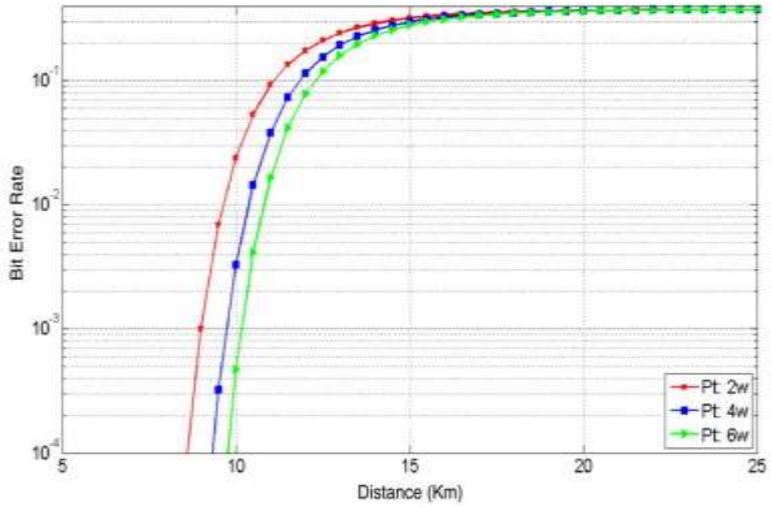


Figure 6: Relationship between distance and water depth for different modulation schemes.

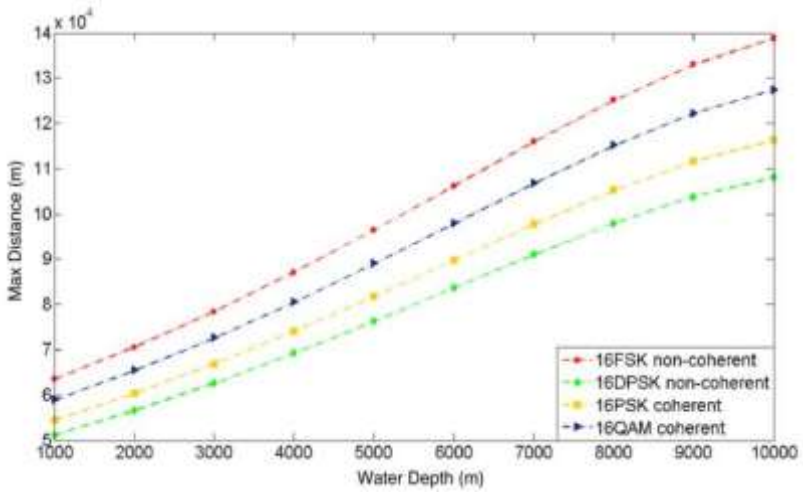


Figure 7: Relationship between distance and BER.

the most suitable modulation scheme is coherent QAM. coherent 16 quadrature amplitude modulation (QAM), which can achieve larger bandwidth efficiency, has the second largest range. BER decreases with increase in transmitted power also in Figure 7. A high ordermodulation scheme requires more transmitting power. Therefore, to achieve the low BER and high bandwidth efficiency,

c. Transceiver design

When acoustic waves are used for wireless underwater communication, a piezoelectric transducer is required at the receiver to convert the sound energy in form of water waves to electrical energy so that the signal can be detected. The factors considered in the design of a transceiver to achieve high throughput with the low BER over band-limited underwater channels include coding and error correction techniques. Burst errors are common in an underwater wireless communication channel due to the fact that there many sources of errors in underwater wireless communication channel as discussed in section 2 of this paper. An interleaver is therefore necessary in the receiver for protection against burst errors. The most suitable coding technique for use in an underwater transceiver is Hadamard coding because it achieves high bandwidth efficiency [17] High bandwidth efficiency arises from the fact that compared to other coding techniques such as LPDC (Low Parity Density Check) [17-18]. Hamadard code can detect and correct the same amount of errors as other coding techniques using a higher code rate. Hamadard coding is also suitable since it can not only detect errors but it can also correct them. Hadamard codes are generated from a Hadamard matrix, whose rows form an orthogonal set of codes.

d. Security Requirements

In UWCNs the following security requirements should be considered. Authentication is a proof that the data has been sent. This is very essential in secured applications of UWCNs. Confidentiality is not to allow any unauthorized person to access the information. Integrity ensured information is not altered. Availability ensures the authorized person accessibility of information.

d1. Secure Time Synchronization

Time synchronization is essential in many underwater applications such as coordinated sensing tasks. Also, scheduling algorithms such as time division multiple access (TDMA) require precise timing between nodes to adjust their sleep-wake up schedules for power saving. For example, in water quality monitoring, sensors are deployed at different depths because the chemical characteristics of water vary at each level. The design of a delay tolerant time synchronization mechanism is very important to accurately locate the water contaminant source, set up the sleep-wake up schedules among neighboring nodes appropriately, and log the

water quality data correctly into the annual database with the accurate timing information. Achieving precise time synchronization is especially difficult in underwater environments due to the characteristics of UWCNs.

For this reason, the time synchronization mechanisms proposed for ground-based sensor networks cannot be applied, and new mechanisms have been proposed.

d2. Secure Localization

Localization is a very important issue for data tagging. Sensor tasks such as reporting the occurrence of an event or monitoring require localization information. Localization can also help in making routing decisions. Localization approaches proposed for ground-based sensor networks do not work well underwater.

Localization schemes can be classified into:

Range-based schemes: The location of nodes in the network is calculated by accurate distance or angle measurements.

- Anchor-based schemes. In this scheme, anchors are placed at locations determined by GPS. The propagation delay between the AUV and the anchors is used to calculate the distance from multiple anchor nodes.
- Distributed positioning schemes; In this scheme, the underwater sensor positioning is proposed as a localization of 3D virtual network. This is then transformed in to 2D by a non-degenerative projection technique. Using the depth of sensor, mapping is done onto the 2D horizontal plane. The trilateration or bilateration methods are used to locate the sensors.
- Schemes that use mobile beacons/anchors: They use mobile beacons whose locations are always known. Every node based on its present location and past location predicts the future location. The knowledge of the surrounding beacons helps it in prediction.

Range-free schemes (not using range or bearing information): They have been designed as simple schemes to compute only coarse position estimates. A range-free scheme Proposed in [15] estimates the location of a sensor within a certain area. None of the aforementioned localization schemes was designed with security in mind. Some localization-specific attacks (replay attack, Sybil attack, and wormhole attack) have previously been described

d3. Secure Routing

Routing is important for packet delivery in UWCNs. Routing is specially challenging in UWCN because the large propagation delays, the low bandwidth, battery refills of underwater sensors, and the dynamic topologies. Hence, routing protocols should be charted to be energy-aware, robust, scalable and adaptive. Although routing protocols have been proposed for underwater wireless sensor networks, none of them have been designed aiming the security. The network's operation can be crippled by the routing attacks. Spoofing, altering , or replaying routing information affects routing. The attacks against routing in UWCNs are the same as in ground-based sensor networks. But, the same countermeasures are not directly applicable to UWCNs as there are differences in characteristics.

V. CONCLUSION

Underwater wireless communication is different from terrestrial wireless communication.It is by far more challenging to design underwater wireless links and also transmitters and receivers. In this article we have briefed security in UWCNs, outlining the specific characteristics of these networks, possible attacks, and their countermeasures. The primary objective is to choose the best carrier frequency so as to minimize transmission energy. QAM is the most suitable modulation technique since it minimizes BER and has a relatively long range. An interleaver and convolution encoders are necessary in the receiver so as to achieve a low bit error rate. Hadamard coding is recommended for use in the receiver because it is bandwidth efficient. The main research challenges related to secure time synchronization, localization, and routing have also been surveyed. These research issues remain wide open for future investigation.

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