DEVELOPMENT OF IMPROVED TECHNIQUES FOR UNDERWATER COMMUNICATION: A REVIEW

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Abstract: *Underwater wireless communication (UWC) is essential to military and civilian communication systems. This article aims to review relevant literature and provide insights on available methodologies and approaches in underwater wireless communication toward developing an improved hybrid underwater communication system. This work analyzes multiple modulation schemes and fading channels suitable for underwater wireless communications that can switch between optical and acoustic modes. This review aims to provide information on effective ways to achieve a better result compared to the existing approaches from related works such that an advanced approach can be developed for submarine communication Engineering. It also seeks to assist underwater communication service providers to be aware of how to bring about the actualization of improved transmission for underwater communication.*

1. INTRODUCTION

For military and civilian purposes, effective underwater wireless communications are essential. In total to submarine communication, underwater communication is similarly valuable for a wide range of civil applications, including ocean exploration, underwater search and rescue, underwater disaster management, offshore oil production, contamination monitoring in ecological schemes, analytical figure collection at deep-sea bottommost posts, message broadcast amid divers, and mapping of the deep-sea level to locate things and discover new resources [1] [2]. The field of military communications that deals with submarine communication faces specific technological difficulties and calls for advanced solutions. Submerged submarines are exempted from radio connection being transmitted at regular radio frequencies since radio waves do not carry penetrable signals over high-quality electrical conductors like salt water [3]. Thus, to use regular radio broadcasts, submarines can raise an antenna on top of the water or float a tethered buoy containing an antenna. Though, this leaves them open to exposure by anti-submarine warfare troops. Due to their slow speed and underwater durability, early World War II submarines spent much of their time on the surface. They only dived to avoid immediate danger or to approach their targets surreptitiously. However, nuclear submarines with extended submergence times were constructed during the Cold War. Submerged ballistic missile submarines must be given prompt orders to fire their missiles in the event of a nuclear conflict. This review focuses on an active area of underwater communication towards achieving a better QoS for voice, data, and image transmission [4][5].

Considering the frequency spectrum, as stated in Tables 1 and 2, for efficient data and voice transmission for underwater communication, navies deploy strong shore VLF transmitters for submarine communications since VLF radio waves may pass through saltwater a few hundred feet (10-40 meters) [6].

Table 1: ITU Classification of Frequency Bands [8]

Frequency Band	**ITU band number**	**Frequency (kHz)**
Extremely low frequency (ELF)	1	0.003 - 0.03
Super low frequency (SLF)	2	0.03 – 0.3
Ultra-low frequency (ULF)	3	0.3 - 3
Very low frequency (VLF)	4	3 – 30
Low frequency (LF)	5	30 – 300
Medium frequency (MF)	6	$300 – 3 \times 10^3$
High frequency (HF)	7	$3 \times 10^3 – 30 \times 10^3$
Very high frequency (VHF)	8	$30 \times 10^3 – 300 \times 10^3$
Ultra-high frequency (UHF)	9	$300 \times 10^3 – 3 \times 10^6$
Super high frequency (SHF)	10	$3 \times 10^6 – 30 \times 10^6$
Extremely high frequency (EHF)	11	$30 \times 10^6 – 300 \times 10^6$
Terahertz or tremendously high frequency (THF)	12	$300 \times 10^6 - 3 \times 10^9$

Table 2: IEEE Classification of Frequency Bands [8]

Frequency range (MHz)	**Wavelength**	**IEEE band**
0.3 - 3	100000 - 10000	MF
3 – 30	10000 - 1000	HF
30-300	1000 - 100	VHF
300 – 3000*	100 - 10	UHF
1000 - 2000	30 - 15	**L** band
2000 - 4000	15 - 5	**S** band
4000 - 8000	5 - 3.75	**C** band
8000 - 12000	3.75 - 2.5	**X** band
12000 - 18000	2.5 - 1.6	$\mathbf{K_u}$ band
18000 - 26000	1.6 - 1.2	**K** band
26000 - 40000	1.6 - 75	$\mathbf{K_a}$ band
40000 - 75000	75 - 4	**V** band
75000 - 111000	4 – 2.8	**W** band
Above 111000	**mm-wave**	

More so, using a buoy with an antenna on a lengthy cable is possible for deeper vessels; the buoy rises to a depth of a few meters and might be too minor for hostile sonar and radar to pick it up. However, due to these depth restrictions, submarines can only receive signals for brief periods. Additionally, antisubmarine warfare may be able to identify the sub or antenna buoy at these low depths. However, excessive radiated power is needed to overcome the natural background noise. More so, traditional antennas are ineffective compared to the reference wavelength, preventing submarines from conveying messages at VLF and making it a one-way communication [7]. This suggests the necessity of extremely powerful transmitters with antennas that cover kilometers of square space. To commune on advanced frequencies, typically HF and beyond, two-way communication requires the boat to climb closer to the surface and deploy an antenna mast, as illustrated in Figure 1.

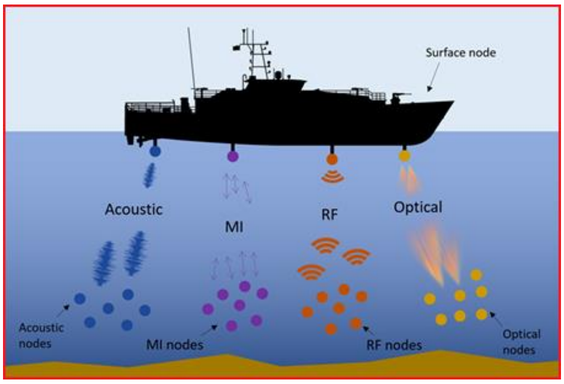

Fig. 1: Two-way underwater communication systems [7]

However, voice transmission is not allowed due to the restricted bandwidths available; thus, only slow data is supported, and data compression is crucial because VLF data transmission speeds are just 300 bps [8]. Therefore, signals can be conveyed to submarines at their working depths using electromagnetic waves in extremely low frequency (ELF) and super low frequency (SLF) frequency ranges (between 3-300 Hz). Due to its requirement to operate at extremely long wavelengths, constructing an ELF transmitter is challenging.

A message can be completed using the ELF transmission technique equally through extremely low signal-to-noise ratios. Since no more than a small virtual arbitrary number of orders corresponds to a real message, there is an extreme likelihood that the information received was an actual message. Link communication is one-way since a submarine could not have an internal ELF transmitter owing to its robust size. Thus, constructing a transmitter that could be submerged in water or flown on an airplane was considered a tacky idea. However, it was the first ever implemented by the US Navy to send commands for proper analysis towards creating alternative communication techniques because of the limited bandwidth. It is realistic to presume that the actual messages were frequently demanded to ascertain a diverse two-way communication method with the relevant authority [9]. A few countries have created transmitters that send data using extremely low frequency (ELF) radio waves that can travel through water and reach submarines at working depths. However, these devices need enormous antennas. Sonar and blue laser are among the other approaches that have been employed.

Generally, underwater wireless communication systems are not simple to erect or build. There are physical difficulties connected with it, such as underwater channel modeling, signal scattering in seas, limited bandwidth, particularly for communication through extended distances, elevated power usage, low SNR, inter-symbol interference (ISI), and multipath channel features with significant tap latency [10]. Due to the extreme diversion and attenuation of electromagnetic waves in underwater channels and the prompt diversion and dispersion of optical waves in such channels, acoustic channels are the most desired channels to use in underwater wireless communications [9]. The Doppler Effect and multipath dispersion are significant problems identified for underwater networking, making computational and realistic physical layer models very hard to achieve. Thus, the physical realization might be cumbersome if no research line gives the details of the best fading channel and modulation techniques suitable for underwater communication to guarantee a better reception of voice, image, and high data rate coupled with spectrally efficient bandwidth management to give a good Quality of Service (QoS) to the submarines users.

2. OVERVIEW OF RELATED WORKS

Underwater communication systems now use electromagnetic, optical, and acoustic data transmission techniques to transfer data between several locations. While optical waves can travel relatively small distances because they are absorbed by seawater, electromagnetic communication techniques are impacted by the conducting property of seawater [11]. Due to reduced mitigation in saltwater, acoustic communication is the only method that performs better when used underwater. Deep, thermally stable oceans also have less attenuation in acoustic communication. Deep water considerably impacts auditory communication due to temperature differences, surface interference from surrounding objects, and the multipath effect caused by reflection and refraction. Ocean bottom sensor nodes can be used for oceanographic data collection, pollution monitoring, offshore exploration, and tactical surveillance applications. Moreover, unmanned or autonomous underwater vehicles (UUVs, AUVs) equipped with sensors can explore natural aquatic resources and gather scientific data in collaborative monitoring missions [7]. Underwater acoustic networking is the enabling technology for these applications. Underwater Networks consist of several sensors and vehicles deployed to perform collaborative monitoring tasks over a given area [4]. The sound speed in an underwater environment is not continuous; somewhat, it changes from place to place. The speed of sound at the ocean's surface is measured to be 1.5×10^3 m/s, which is a quarter more rapid compared to sound speed in air. However, it is much slower than the electromagnetic and optical speeds in air, which are 3×10^8 m/s and 3×10^8 m/s, respectively.

In the case of an underwater environment, both artificial and natural acoustic systems make use of an acoustic channel. Because both acoustic systems use a lot of middle frequencies, their communication is impacted by each other because they use the same frequencies. The range of auditory channels is still not being used effectively. Cognitive Acoustic (CA) is a technique presented by authors in [12] as a possible way to construct a friendly environment for underwater acoustic networks (UAN) through elevated spectrum utilization. This method can logically sense if another party uses a portion of the spectrum. It may also modify its power, frequency, or further operative characteristics to utilize the vacant frequencies for a short while without obstructing other system networks. The CA approach prevents interference with marine mammals, resulting in a friendly and error-free communication environment. Low data rates in underwater environments are caused by using low frequencies, which is a significant problem. Other issues, including energy scattering and reflection, also lower the performance of devices. The author of this research proposed a model for underwater communication that produced extreme data rates even when observing wireless sensor node performance set up on various frequencies [4].

Due to specific difficulties, such as limited bandwidth, lengthy propagation delays, fluctuating sound speed, reflection, refraction, and significant propagation losses, acoustic channels are incredibly changeable. These difficulties also lead to issues with media access control techniques. Two primary types of Media Access Control protocols are contention-based and scheduled. While contention-based protocols pit nodes against one another to share a single channel, scheduled methods prevent collisions between transmission nodes. Code Division Multiple Access (CDMA) is appropriate for underwater acoustic system networks, whereas frequency Division Multiple Access (FDMA) is unsuitable owing to its limited bandwidth. Programmed-based protocols, such as Time Division Multiple Access (TDMA) [13], are ineffective due to significant transmission latency. [14] present the TDMA-based Underwater Acoustic Channel Access Control technique (UA-MAC) to increase channel utilization in dense Mobile Underwater Wireless Sensor Networks (MUWSN), notwithstanding contention-based protocols are inappropriate for underwater communications [15] The goal is to resolve issues such as end-to-end delays, concealed terminal problems, and time schedules for channel access. The piggyback system is implemented via the underwater acoustic channel access technique, which reduces the number of packets transferred. That kind of approach reduces collision and conserves a great deal of energy. Since no solitary protocol can fully satisfy the underwater sensor network media access control criteria, the authors in [16] incorporate many media access control protocols in an Adaptive Multimode Medium Access Control for Underwater Acoustic Networks collection. Adaptive Multimode Medium Access Control for Underwater Acoustic Networks aims to enhance traffic intensity performance. Depending on the demands of the network, traffic volume, and quality of service, this suite alternates between protocols.

Temperature, height (depth), transmission forfeiture, and ambient noise in the underwater environment, wherever sensor nodes are positioned, all impact channel capacity. The relationship between path loss and the communication frequency and space (connecting two nodes) is known. Acoustic channel capacity is affected by these variables. Nevertheless, bandwidth falls with increasing distance and depth and rising temperature. To improve channel capacity and throughput rates, the authors in [17] found that acoustic channel capacity increases when temperature and depth are increased over short distances. High bit error rates and latency characterize acoustic channels; to end the lengthy latency and high bit error rates as well as to increase channel usage, authors in [13] and [18] evaluate three distinct approaches: adaptation of packet train size, forward error correction, and packet size adaptation. While packet size adaptation and forward error correction solve together equally massive propagation delays and bit error rates, packet train length overcomes both long transmission latency and time wastage. Under the use of forward error correction and packet size modification, acoustic channel use also rises. Harris's analysis offers recommendations for media access control and routing protocol development. Only when localization is involved is sensor node information meaningful. Numerous terrestrial localization techniques exist, but they cannot be easily applied to underwater sensor networks due to specific constraints (sensor nodes moving with ocean currents, high sensor node costs, global position system inappositeness, and restricted battery power).

Anchor-Free Localization Algorithm (AFLA) is a localization method described by [19]. This algorithm is capable of self-localization for sensor nodes without anchors. To limit sensor nodes in an underwater environment, AFLA uses cables and anchor nodes. Developing an effective localization strategy for underwater sensor networks is the aim of AFLA. Corresponding to simulation data, AFLA is a reliable localization system that works well in static and dynamic network scenarios [20]. Significant problems like energy saving and mobility concerning underwater sensor networks provide difficulties for designing routing protocols and render all currently used ground-based routing techniques (both proactive and reactive) insufficient. protocols that are energy-efficient, control random fluctuation in topology, and consider asymmetric links and significant propagation delay are necessary for the underwater environment. A methodology called Level-Based Adaptive Geo-Routing (LBAGR) is presented by authors in [21]. and it separates communication traffic into four groups. They are downstream to sensor nodes, downstream to all nodes, downstream to sink, and downstream to specified nodes. Density, battery power availability, and level linking neighbors are the factors that are utilized to determine the next optimal hop in data forwarding. The objectives of Level-Based Adaptive Geo-Routing are to minimize communication latency and energy consumption and enhance the delivery ratio and percentage of received packets. With this protocol, end-to-end communication latency is decreased, delivery ratios are increased, and battery power is used more effectively. The primary goal of underwater sensor network routing protocols is to maximize battery life.

To forward data to the surface sink, the study in [22] developed a routing protocol that effectively uses energy by employing decision trees and fuzzy logic approaches. The purpose of routing protocol is to use battery power as efficiently as possible to minimize energy consumption during acoustic transmission. The protocol lowers energy consumption and traffic overload on the acoustic channel. Underwater sensor networks now require excellent efficiency and minimum end-to-end delay for routing methods. An end-to-end delay is presented by [23]. The Diagonal and Vertical Routing Protocol aims to reduce sensor node battery power consumption and end-to-end delay. Large routing tables are unnecessary for the Diagonal and Vertical Routing Protocol to maintain; instead, they leverage local information to route data packets to their intended destinations. There is no disruption to already-existing nodes when new nodes are added or removed. Two protocols are chosen by authors [24] by adjusting the packet size, bit error rate, and traffic load; these two protocols—Code Division Multiple Access (CDMA) and Distance Aware Collision Avoidance Protocol (DACAP)—are evaluated. The author ascertains the effect of packet size on multi-hop underwater sensor networks by utilizing varying packet sizes, bit error rates, and traffic load. Different fixed (predetermined) packet sizes were used in an experiment by authors in [15], and the packet size remained constant regardless of the surrounding conditions. Because data and control packets collide, the entire packet is destroyed, resulting in significant re-transmissions and energy loss. Data packets are sufficiently large in comparison to control packets.

Data fragmentation is a technique introduced by authors in [24]; the method divides large data packets into smaller pieces to minimize the risk of collision. The approach is tested on DACAP with and without consideration for data fragmentation. In addition to reducing overall traffic and significant overhead, fragmentation reduces packet latency, energy consumption, and retransmissions. The notion that interference and fluctuating bandwidth cause traffic loads to grow on a congested communication channel is overlooked by authors in [15],[24]. Thus, enhancing the throughput of a single hop packet size is a crucial factor in communication inside the underwater sensor network domain. Optimal packet size selection can help avoid underwater sensor networks' half-duplex communication methods. Sensor nodes in this suggested feeding control system collaborate to make the appropriate decisions. This system's role is to prevent food loss, lessen adverse environmental effects, and make the system economically viable. In reference [5], the proposal of QERP aims to increase the data transfer reliability in underwater acoustic sensor networks. Sensor nodes are arranged using a hierarchical network of small clusters connected in an even distribution of data and energy. In an underwater setting, this method maintains good link quality while lowering the likelihood of packet loss. The problem with the above technique is that node density and mobility are not considered [25].

The functioning of multi-hop networks concerning throughput, energy efficiency, and latency is observed by authors in [24]. The impact of bit error rate, interference, collision, and retransmission on the optimal packet size selection process is also considered. The two media access control protocols, CDMA and DACAP, are chosen based on the study in [15]. They then compare the outcomes, alter the network deployment scenario, and see how packet size affects throughput, energy efficiency, and network latency. All metrics, including throughput, energy consumption, resource use, and packet latency underutilization of optimal packet size selection, are improved by the study reported in [26] based on the investigation of energy efficiency using the NS-2 simulator and the ideal packet size reported in reference [13]. The authors build a network with 100 nodes that are 2 km by 2 km by 200 m in size. The experiment demonstrates an association between energy efficiency and packet size. The ideal packet size minimizes the use of excess energy. Adopting the perfect packet size for an erroneous channel minimizes energy waste, even when an erroneous channel has a high bit error rate that results in significant energy waste. Because of the highly variable environment, underwater sensor networks pose a substantial risk to dependability (as regards data delivery).

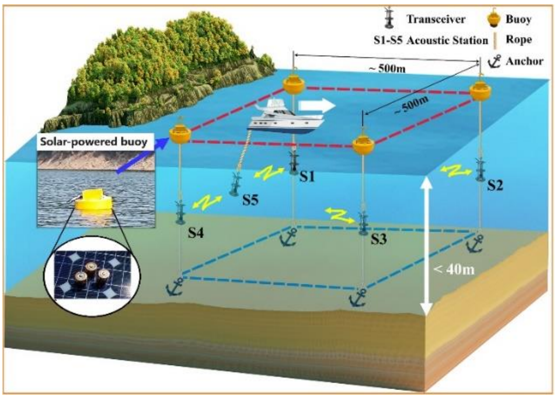

Fig. 2: Illustration of UWSN sensor nodes arrangement and distribution [27]

The study in [28] presents a technique that uses the two-hop approach for the same packet size to identify the optimum acceptable packet size for dependable data transport. An algorithm looks at the best data packet size for networks of underwater sensors, using energy efficiency as the optimization parameter. The procedure’s main objective is to transfer data reliably from the transmitting node to the receiving node or surface sink, a crucial network component. This portion of this research summarizes the many developments in Underwater Wireless Sensor Networks (UWSN) that communicate via acoustic channels, as illustrated in Figure 2. The summary of some reported studies on UWSN is shown in Table 3. Despite this, there are still a few problems and restrictions associated with UWSN. This review paper aims to address these issues and limitations by investigating acceptable strategies that can be used to improve underwater communication.

Table 3: Summary of review articles on recent developments in underwater wireless sensor networks

Ref.	Title	Research focus and findings	Gap
[2]	Challenges: Building Scalable and Distributed Underwater Wireless Sensor Networks (UWSNs) for Aquatic Applications,	The research focused on the UWSN protocol; it was observed that CDMA is the only protocol from the Schedule-based protocol that is suitable for acoustic networks. Contention-based protocols are not appropriate for underwater communications.	Noise, BER, and modulation schemes were not analyzed and estimated.
[7]	Prospects and Problems of Wireless Communication for Underwater Sensor Networks	The research shows that Acoustic communication also has few attenuations in deep and thermally stable oceans. The findings show that shallow water alters acoustic communication by temperature gradients and ambient noises as regards shallow and multi-path effects due to reflection and refraction.	UWNS and protocols were not analyzed regarding fading due to the natural challenges of water.

[41]	Analyzing the Performance of Channels in Underwater Wireless Sensor Networks (UWSN)	The research findings show that multi-path propagation causes fading and phase fluctuations, and the Doppler Effect is detected owing to the movement of the sender and receiver nods. Sound speed and underwater noise are added factors that influence the performance of underwater communication	Energy efficiency, BER, and UWN modulation schemes were not analyzed.
[12]	Optimized packet size selection in underwater wireless sensor network communications	The research findings show the effect of bit error rate, interference, collision, and retransmission leading to the selection of optimal packet size and achieving improvement in all metrics, e.g., throughput, energy consumption, resource utilization, and packet latency underutilization of optimal packet size selection	Natural challenges for UWC were not analyzed for proper fading estimation
[14]	Choosing the packet size in a multi-hop underwater network	The focus of the research shows that Data packets are sizeable compared to control packets because of control and data packet collision.	Protocol, fading, Noise, BER, and modulation schemes were not analyzed and estimated.
[2]	Challenges for efficient communication in underwater acoustic sensor networks	The primary area focus of this research is the major cause of weakness faced in the acoustic signal, which is mainly influenced by the multi-path effect, which becomes the cause of inter-symbol interference; it also makes acoustic data transmission challenging and inaccurate. It was deduced that the multi-path effect alters the vertical acoustic channel compared to the horizontal acoustic channel.	BER, Protocol, and fading are not considered for better performance or QoS
[42]	Ocean ambient noise: Its measurement and its significance to marine animals	The deduction from the research findings shows that many ships present at sizeable intervals from the communication system in the ocean create extreme traffic noise in acoustic communication.	BER was partially analyzed, but the result was a bit high, which caused low QoS and fading; the modulation scheme, UWSN protocol, and energy efficiency were not estimated/analyzed
[43]	Doppler estimation and correction for shallow underwater acoustic communications	Because of channel errors, the research findings show that Wireless signals activate a diversity of degradations. For example, electromagnetic signals are affected by interference, reflections, and attenuation, and acoustic signals underwater are also affected by the same factors.	Energy efficiency, BER, and UWN modulation schemes were not analyzed.
[38]	Study on Doppler effects estimate in underwater acoustic communication	The research focused on categories of changes noticed in the acoustic channel because of the Doppler Effect; the study indicates that pulse width must be compressed or stretched and then frequency offset, which results in the signal time domain.	Natural challenges for UWC were not analyzed for proper fading estimation, and modulation scheme, BER, QoS, and energy efficiency were not considered.
[37]	A review of underwater communication system.	The research was focused on reviews of underwater communication techniques with their limitations and benefit. Signal transmission via Acoustic, optical and electromagnetic waves for underwater communication was duly analyzed.	Hybrid underwater communication system that caters for limitations of each of the focused techniques was not analyzed.
[1]	Underwater communication: A detailed review	The research focused on the overview of the underwater communication under various technologies. Factors with respect to QoS for underwater communication was mentioned but not analyzed.	Digital modulation schemes for data transmission with respect to technological advancement in the area of underwater communication was not analyzed

3. REPORTED METHODOLOGIES

3.1 Underwater Acoustic Communication Model

A sound speed profile (SSP) acoustic model for underwater communication environments in 1000 meters of water is defined by Equation (1):

$$\mathrm{B} = 0.016\mathrm{Q} + 4.6\mathrm{t} + 1449.2 + 0.00029\mathrm{t}_3 - 0.055\mathrm{t}_2 + (\mathrm{A_s} - 35)(1.34 - 0.01\mathrm{t}) \qquad (1)$$

where B represents speed for acoustic wave, t is channel temperature, As is water salinity, and Q is the depth of the waterbed.

One barrier brought on by disturbance at sea level is scattering loss. A simplified model explains how absorption as well as spreading losses will amount to loss of route as shown in the Equation (2):

$$10\log\mathrm{A}(\mathrm{l}_0, \mathrm{f}_0) = 10\log(\mathrm{A}_0) + (\mathrm{l}_0) * 10\log\mathrm{a}(\mathrm{f}_0, \mathrm{S_a}, \mathrm{T_c}, \mathrm{d}, \mathrm{H_d}, \mathrm{z}) + 10\mathrm{k_t}\log(10) \qquad (2)$$

where l_0 denotes space amid receiver and transmitter in (m), f_0 denotes frequency range (KHz), and k_t denotes spreading factor. For cylinder-shaped, k_t=1 and sphere-shaped, k_t =2. A_0 is the normalizing factor, d represents the split-up distance between the receiver and transmitter, S_a is salinity (ppt), T_c is temperature (0^c), and H_d is water depth in (m).

Due to seawater's absorption, underwater acoustic communication has a far smaller absolute bandwidth than terrestrial communication; an increase in spectrum and frequency will cause attenuation to rise. According to Table 1, the typical frequency range for acoustics is (8000-14000) Hz, through a few Km bands [8]. Before approaching the receiver in wireless situations, a sent signal may experience several scatterings. Fading is a phenomenon that results from these random oscillations in the received signal. The following is a discussion of the fading distributions that are suggested for use in this research:

3.2 Rayleigh Fading Model

Signal disruption is a no line of sight (NLOS) component. If there are many NLOS components, the fading process can be roughly described as the summation of many complex Gaussian processes whose probability-density function is Rayleigh distributed as expressed in Equation (3). The equivalent baseband signal can then be expressed mathematically as a Rayleigh fading modeled and described in Equations (4), (5), and (6) [29].

$$\mathrm{Z_r}(\mathrm{t}) = \mathrm{A}(\mathrm{t}) + \mathrm{M_s}(\mathrm{t}) * \mathrm{M_d}(\mathrm{t}) \qquad (3)$$

where: A denotes Additive White Gaussian Noise (AWGN), M_s denotes message signal, M_d denotes modulated signal, and Z_r denotes received signal.

$$R_m(t) = \sum_k \alpha_k(t)\, \ell^{-j2\Pi f_c \varphi_{(t)}} \qquad (4)$$

$$R_{(r)} = \frac{q}{\sigma^2}\, \ell^{-\frac{q^2}{2\sigma^2}} \qquad (5)$$

$$E\left(q^2\right) = 2\alpha^2 \qquad (6)$$

Where:

$\frac{q^2}{2}$ - instantaneous power q ≥ 0

σ - root mean square (rms) value of receive signal

σ^2 - is the local average power of the received signal envelop detection

α_k - is the time-varying attenuation factor of the ith propagation delay, fc is the carrier frequency, and is the time-varying delay. The assumption is that φ_i << T and T is the symbol time.

In reference [30], the central limit theorem applies when the delays φi (t) fluctuate randomly and when there are several propagation paths, and $R_m(t)$ may be treated as a complex Gaussian process. The Rayleigh pdf's probability density function is shown when the $R_m(t)$ components are independent. Power is uniformly distributed and has an exponential distribution, while phase has no correlation to amplitude. Rayleigh fading distribution is the leading model utilized the most in wireless communications. However, because there is no Line-of-Sight (LOS), it is the worst-case scenario for fading.

3.3 Rician Fading Model

Since there isn't a clear line of sight (LOS) path connecting the transmitter and the receiver, the Rayleigh distribution works effectively in this situation. If a line-of-sight route exists, the multipath scattering is no longer Rayleigh but Rician. In reference [31], the baseband fading process can be represented and expressed mathematically in Equations (7), (8), and (9) if the LOS component reaches the receiver. For dominating LOS medium, the fading technique is the product of a multiplex exponential process with a narrowband multiplex Gaussian process.

$$R_{(f)} = \frac{q}{\sigma^2} \ell^{-\frac{q^2+\gamma}{2\sigma^2}} J_o \left[\frac{\Gamma\gamma}{\sigma^2} \right] \quad (7)$$

$$2\sigma^2 = E\left(\psi^2\right) \quad (8)$$

$$Z = \frac{\gamma}{2\sigma^2}^{2} \quad (9)$$

Where:

J$_0$ is the modified Bessel function of zero-order

$2\sigma^2 = E\left(\psi^2\right)$ is the Rice factor

$Z = \frac{\gamma}{2\sigma^2}^{2}$ is the relation between the power of the LOS component and the power of the Rayleigh component when Z $\rightarrow \infty$, no LOS component, then Rayleigh is equal to the Rician PDF

$\frac{q}{2}^{2}$ - instantaneous power

σ - standard deviation of the local power

σ^2- is the local average power of the received signal envelop detection

q - is the amplitude of the received signal

3.4 Nakagami Fading Model

According to reference [32], multipath dispersing, several wave collections, and moderately large delay-time disperse bring about the Nakagami fading scenario. Each reflected signal's phases change randomly within each cluster, but every signal delay time is approximately equivalent. To replicate the Nakagami distribution, which includes both the Rayleigh and Rician distributions, equations (2) and (5) were adopted to create a Nakagami fading envelope. If the number of NL0S paths, N, is too small, the outcome will not be correct. During the research study simulation, the value of N will be determined. Equation (10) is the Nakagami fading model mathematical expression:

$$R_{(t)} = \frac{2}{\Gamma_{(m)}} \left(\frac{M}{2\sigma^2} \right)^m q^{2m-1} \ell^{\frac{mq^2}{2\sigma^2}} \quad (10)$$

Where $2\sigma^2 = E\left(q^2\right)$, $\Gamma(.)$ is the gamma function and $m \geq \frac{1}{2}$ is the fading figure (degrees of freedom related to the number of added Gaussian random variables). When m =1, Nakagami degraded to Rayleigh.

3.5 Hoyt Fading Model

The Hoyt fading distribution, similarly classified as the Nakagami-q fading distribution, is frequently used to characterize a short-term signal transformation in a particular multipath propagation of a wireless communication system. The Probability Density Function (PDF) of Hoyt fading distribution can be modeled mathematically as expressed in Equation (11) [32] [33].

$$S_{nakag(v)} = \frac{V}{\sigma_1 \sigma_2} \ell \left[\frac{V^2}{4} \left(\frac{1}{\sigma_1^{\ 2}} - \frac{1}{\sigma_{_2}^{\ 2}} \right) l_0 \left(\frac{V^2}{4} \left(\sigma^2{}_2 - \sigma_1{}^2 \right) \right) \right] \quad (11)$$

where; l_0 (.) denote the zeroth order modified function of the first kind, V is the amp of the received signal σ_1 and σ_2 are the zero mean and variance, respectively.

In addition, the Hoyt channel is described as a more severe fading scenario than those modeled by Rayleigh in satellite-based cellular communications. In this study, Hoyt fading is suggested as a novel advancement in submarine communication engineering for application in underwater acoustic communication.

3.6 Log-Normal Fading Model

Significant elements contributing to radio waves' scattering and absorption include vegetation and foliage. As a result, the received signal power fluctuates approximately as expected by the signal strength reduction [34]. The mean signal power fluctuates randomly due to fading over long distances, and these fluctuations have a log-normal distribution, as expressed in Equation (12). The equation gives the Probability Density Function (PDF) of the received signals envelope of this distribution and is modeled mathematically as:

$$P_r(\gamma) = \frac{\xi}{(2\pi\gamma\sigma)^{\frac{1}{2}}}\ell\left(-\frac{10\log_{10}\gamma-\mu}{2\sigma^2}\right)^2 \quad (12)$$

where; γ is the amplitude of the received signal, σ and μ are the mean and standard deviation of $10\log_{10}\gamma$, respectively.

3.7 Weibull Fading Model

The Weibull fading distribution model is another generalization of the Rayleigh fading distribution. The Weibull distribution is an experimental spreading, initially used as a numerical standard for dependability study. Its austerity and flexibility rapidly enhanced its path to wireless communication applications [35]. The fading model for the Weibull distribution cogitates a signal as the collected constellation of multipath waves spreading in a non-homogeneous environment. Within this cluster, the phases of the dispersed waves are arbitrary. The resultant envelope is obtained as a non-linear function of the modulus of the sum of the multipath components. Equation (13) is the corresponding Weibull mathematical expression from the Rayleigh distribution envelope, and Equation (14) is the corresponding pdf distribution given, respectively.

$$R = \left(U^2+V^2\right)^{\frac{1}{m}} \quad (13)$$

The corresponding pdf distribution (for the Weibull fading model is given and mathematically expressed as:

$$f_{(r)} = \frac{mq^{m-1}}{2\sigma^2}\ell^{\frac{q^m}{2\sigma^2}} \quad (14)$$

where; $2\sigma^2 = E\left(q^2\right)$,U and V are zero-mean Gaussian variables.

4. DIGITAL MODULATION TECHNIQUES

High data size, increased data protection, and prompt system accessibility, alongside exceptional message transmission, are all benefits of digital modulation. Subsequently, digital modulation techniques are in higher demand due to their capability to transfer larger volumes of data than analog modulation techniques. Modulation is the method of imprinting the data to be transmitted on the radio carrier; it is the basis of all wireless communications. Owing to the limited frequency band presently available, digital wireless transmissions are eminent today, causing modulation to be significant [36]. The fundamental aim of modulation is to incorporate extensive data as feasible into the smallest quantity of spectrum. Spectral efficiency measures the data speed in a specified bandwidth, measured in bits second hertz (b/s/Hz). One of the aims of this research is to achieve spectral efficiency with bandwidth management. Depending on the situation, there are a variety of digital modulation techniques and their groupings; of them all, the discussed are the ones proposed to be used in this research work.

4.1 Quadrature Amplitude Modulation (QAM)

Quadrature Amplitude Modulation (QAM), which merges phase and amplitude modulation techniques, is one of the most extensively utilized schemes. Quadrature amplitude modulation is a technique that can extend the idea of conveying more bits per symbol by producing symbols that have an approximate combination of amplitude and phase (QAM) [31]. Like other modulation techniques, QAM modulates the carrier wave in response to the carrier signal to transmit data. When using QAM, the data signal is represented by altering the amplitude of two waves that are 90° apart. Phase and amplitude modulation of a single carrier can be viewed as equivalent when two carriers are modulated in quadrature.

Regardless of QAM's remarkable spectrum efficiency, noise, which entails mainly arbitrary amplitude variations, causes demodulating the signal extra exigent. Cable TV, Wi-Fi wireless local-area networks (LANs), satellite broadcasting, and cellular mobile use QAM to maximize data rate in constrained bandwidths. In QAM, incoming bits are mapped into two base signals as Equation (15) mathematically expressed

$$S_i(t) = \sqrt{\frac{2E_i}{Ts}} \cos 2\pi\, fc(t) - \frac{2\pi i - 1}{M} \quad 0 \le t \le Ts \qquad (15)$$

One of *M* possible value $\frac{2\pi i - 1}{M}$ is taken by the carrier phase, where *i=1, 2, ..., M*, and *Ei = Es*, when *i = 1, 2, ..., M.*

4.2 Filter bank multicarrier (FBMC)

The FBMC solution is the model filter for the zilch frequency carriers, and it forms the basis for the other subcarrier filters. Filter banks divide the spectrum equally by dividing a signal into sub-bands of various frequencies. The overlapping factor M defines filters when multicarrier symbols coincide in the time domain [37]. While using this prototype filter, the FBMC offers good side lobe attenuation, which improves spectral performance. Perhaps a better prototype filter can only be built using overlapping factor *K*, but in this case, the FBMC offers distinctive side lobe attenuation; however, using this prototype filter also improves spectral performance. Equation (16) is the mathematical model expression and is given as

$$T_{(s)} = \sum_{m=0}^{m-1} \sum_{m=0}^{m-1} P_{o,q}(t) R_{s,u} \qquad (16)$$

where $T_{(s)}$ is the transmitted signal of the multicarrier system and $R_{s,u}$ denote the transmitted symbol at subcarrier position s and time position u. Equation (17) expresses $P_{o,q}$, which denotes the transmitted basis pulse as,

$$P_{o,q}(t) = P\left(t - MT\right) \ell^{\,j2\pi\left[F\left(t-MT\right)\right]} \ell^{\,j\theta su} \qquad (17)$$

4.3 Generalized Frequency Division Multiplexing (GFDM)

Generalized Frequency Division Multiplexing is known as GFDM. It is among the top 5G physical layer solutions since it can handle various requirements [38]. A versatile multicarrier modulation technique is GFDM. Each GFDM data block has a specific integer of subcarriers and sub-symbols, and the modulation is carried out block by block for each data block. Single-carrier frequency domain equalization (SC-FDE) and Cylic-prefix (CP-OFDM) are permitted as exceptional cases of GFDM by placing the integer of subcarriers and the integer of sub-symbols to 1, respectively. GFDM is modeled using the mathematical model given in Equation (18). In addition, GFDM offers the flexibility of pulse shaping with a model filter to lessen out-of-band (OOB) emissions. Circular convolution is employed in GFDM instead of the linear convolution used in FBMC.

$$x_{k(n)} = \left[g^{n!} \otimes \sum_{m=0}^{m-1} dk\left[m\right] \delta\left[n^{!} - mk\right] \right] \ell^{\left(j2\pi \frac{kn}{k}\right)} \qquad (18)$$

where $\otimes$ denote the circular convolution with respect to block length, *N*, and $n^{!}$ is the convolution index variable expressing the convolution explicitly and superposition of $x_{k(n)}$.

4.4 Orthogonal Frequency-Division Multiplexing (OFDM)

In a multi-carrier modulation method called orthogonal frequency-division multiplexing (OFDM), information in data form is transmitted as a combination of orthogonal narrowband signals termed subcarriers. Since OFDM is modeled on single carrier modulation, like QAM, it may transmit information at a comparable proportion. Nevertheless, OFDM brings about receiver equalization and is resilient to frequency selective fading. Wireless communication technologies, like Wi-Fi, LTE, and 5G, use the rudimental design of OFDM. The OFDM data transmission method comprised several parts. Initially, the data is modulated and coded, generally into QAM symbols. These symbols are stored in evenly spread-out frequency bins; an inverse fast Fourier transform (IFFT) converts the signal into orthogonal overlapping sinusoids in the time domain, as given in Equation (19). The equation gives the IFFT as given below:

$$X_{(n)} = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X\left(k\right) \ell^{\left(\frac{j2\pi nk}{N}\right)} \qquad (19)$$

where *X(k)* denotes the transmitted signal, *K* is the Index of the subcarrier of an OFDM symbol

$K = 0,1, \ldots, N\text{-}1$, N is the total number of subcarriers, and X is the amplitude of subcarrier $n = 0, 1, \ldots, N\text{-}1$.

Single OFDM digit consists of the N samples at the IFFT's output. Then, each OFDM digit symbol is given a cyclic prefix to permit the computation of circular convolution through linear convolution against extended channel impulse response [39]. By applying a simple, complex scalar multiplication to each OFDM symbol distinctly, equalization at the receiver can remove inter-symbol interference. Known pilot symbols are typically added to the transmitter in an OFDM application to aid channel estimation and equalization.

4.5 Spectrally Efficient Frequency Division Multiplex (SEFDM)

SEFDM has several carriers like OFDM, but they are placed closer together. If used as an air-interface technique or for backhauling signals over wireless and/or wired and fiber communication channels, spectrally efficient frequency division multiplexing (SEFDM) will pose substantial bandwidth reduction improvement in imminent wireless systems [40]. This research suggests a non-orthogonal multicarrier system, SEFDM, that maintains a similar transmission frequency for each subcarrier while packing subcarriers at a frequency demarcation lower than the symbol rate. Equation (20) is the model equation for SEFDM expressed as:

$$X = \frac{1}{\sqrt{Q}} \sum_{n=0}^{N-1} Z_n \ell^{\left(j2\pi\alpha\frac{qn}{Q},\, 0\le q\le Q-1\right)} \qquad (20)$$

where $\frac{1}{\sqrt{Q}}$ denote normalization factor, α denote compression factor (0,1), N is the subcarrier of the SEFDM symbol and $Z = (Z_0, Z_1 \ldots\ldots\ldots Z_{n-1})$.

5. CONCLUSION

This review paper aims to create a knowledge base for developing improved transmission techniques for underwater communication. In this article, verified theoretical framework and veritable research gaps have been identified for further analysis towards achieving better underwater signal transmission compared to the result from related works that have been reviewed. The information provided in this article can assist researchers in having a fundamental understanding of existing and projected approaches for better underwater communication. It can also help submarine communication engineers and the service provider gain insight into how to develop and bring about the physical realization of an improved transmission for underwater communication systems. of existing and projected approaches for better underwater communication.

In conclusion, the field of UWC has seen significant advancement in recent years, but there's still ample scope for further improvement in signal transmission. The challenges posed by underwater environments, including high attenuation, multipath fading, Doppler shifts, and limited bandwidth, are the areas of research that require adequate study. Thus, future research efforts will focus on enhanced signal transmission strategies to ensure reliable and efficient communication in the challenging underwater communication environment through optimizing modulation schemes, exploring the potential of various fading channels, and investigating advanced frequency bands and signal algorithms.

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