

BER Analysis of Underwater Acoustic Communication using OFDM

Srinivas C ¹, Samundiswary Punniakodi ²

^{1,2} Department of Electronics Engineering, Pondicherry University, Puducherry, India.

Email Id: ¹ srinivasc448@pondiuni.ac.in, ² sam.dee@pondiuni.ac.in

Abstract

Seventy-one percent of the Earth's surface is covered by water, with oceans and seas making up an astounding 96.5 percent. This indisputable fact emphasizes the importance of investigating these unexplored underwater areas for vital purposes, including researching marine life, controlling pollution, keeping an eye on natural disasters, and exploring oil and gas. Electromagnetic, optical, and acoustic waves can communicate underwater successfully; acoustic communication is the most popular option. Improved security, cost-effectiveness, and environmental sustainability are just a few of its many benefits. Even though it faces difficulties, including slow data speeds and constrained capacity, these problems are being methodically fixed. Techniques like MultiCarrier Modulation (MCM), particularly Orthogonal Frequency Division Multiplexing (OFDM), offer workable answers to these problems. This study fully covers Bit Error Rate (BER) analysis in underwater acoustic communication using OFDM and compares BER results between different modulation schemes used in OFDM.

Keywords: Underwater Acoustic communication (UWAC), Bit Error Rate (BER), Signal Noise Ratio (SNR), Inter Carrier Interference (ICI), Carrier Interference Ratio (CIR), Fast Fourier Transform (FFT).

1. Introduction

The vast underwater world, which covers 71% of the Earth's surface with 96.5% oceans and seas, has enormous potential for research and underwater activities such as natural catastrophe surveillance, environmental impact surveillance, marine life, and military applications. This in turn inspired the researchers to conduct research in underwater communication by these initiatives [1]. Underwater communication can be accomplished in three ways: optical waves, acoustic waves, and radio waves. Optical waves are prone to dispersion and absorption, while radiofrequency waves are readily attenuated [2]. Thus, underwater sound communication, which can travel great distances, is a workable answer to the issue above. However, there are certain hurdles to underwater acoustic communication, such as background noise, slow propagation speeds, and multipath propagation [3]. One of the solutions, such as equalization, can be used to overcome ISI caused by multipath[4]. By converting the frequency-selective channel to a flat subchannel, parallel collection of frequency UWA OFDM can prevent multipath fading [5] and reduce multipath latency using a guard band and adequate bandwidth. Furthermore, the MCM technique, like OFDM, is utilized with underwater

acoustic communication to address the above issues while maintaining high data rates and high-quality wireless communication.

The Doppler effect and impulsive noise can hurt UWA OFDM performance. To avoid the doppler effect, a Joint channel estimation and carrier interference reduction utilizing a pilot subcarrier is used, which can overcome the Carrier Interference Ratio (CIR) and avoids the phase noise, and multipath [7]. Two compressed sensing-based algorithms are used to overcome impulsive noise, which estimates both the CIR and the impulsive noise using the pilot subcarrier [8]. Despite the noise being reduced, the BER performance is still very high. The BER performance can be improved by combining OFDM and Direct Sequence Spread Spectrum (DSSS) based on receiver signals [9]. The Irregular Repeat Accumulator (IRA) code can be used with longer code lengths to accommodate channel temporal variability in OFDM, which can improve both BER and SNR[10]. A non-coherent detection scheme like Differentially Encoded Quadrature Phase Shift Keying (QPSK), OFDM is used to increase the BER [11]. Apart from this, we can use modulation in conjunction with coding methods such as BPSK, QPSK, and Quadrature Amplitude Modulation (QAM), with Reed Solomon (RS), Turbo codes [12] to improve BER.

Further, the angle of arrival of the significant propagation path technique is employed in transmitting beamforming which will make the signal to fluctuate gradually rather than rapidly, which can withstand lengthy feedback delays and improve BER [13]. When the multipath spread of the channels is less than the symbol duration, the UW OFDM splits the available bandwidth into sub-bands that overlap. By removing the ISI, this multipath spread over the channel might increase the bandwidth (BW) and improve BER [14]. Precoded Index Modulation (IM) IM-OFDM-Spread Spectrum is proposed for underwater acoustic communication, which improves transmission efficiency by utilizing spreading and multipath diversity while decreasing peak-to-average power Ratio (PAPR) [15]. The spread spectrum multicarrier modulation technique can be used in OFDM, which can assist in reducing errors in underwater channels, thereby improving BER and PAPR [16]. Discrete Fourier Transform (DFT) and Discrete Cosine Transform (DCT)-based OFDM is presented by UWAC, which can decrease the long delay spread and frequency-selective multipath fading resulting in improved performance DCT than DFT in terms of BER and PAPR [17]. The frequency-selective channel can be transformed into a flat sub-channel using the OFDM approach, which lessens the impact of multipath fading [18]. In terms of resilience against the wide multipath spread, UWA OFDM can provide superior performance [19]. Underwater audio communication compares various Spread-OFDM (SOFDM) approaches, the results show that SOFDM gives better results in terms of BER when transmit diversity schemes are used [20].

The Carrier Interferometry code SOFDM approach operates well in terms of BER when compared with Walsh Hadamard SOFDM in UWA communication [21]. Multi-input and Multi-output Non-Orthogonal Multiple Access Filter Bank Multi-Carrier (MIMO NOMA FBMC) is used for waveform shaping to improve throughput and gives best result in terms of BER for multiuser UWAC, when compared to OFDM alone [22]. Fast Walsh-Hadamard transform (FWHT) is utilized to enhance BER rather than the Fast Fourier transform (FFT) in UWAC [23]. A non-OFDM approach where the receiver with Orthogonal Matching point in underwater acoustic communication receiver outperforms OFDM in terms of BER [24]. For underwater acoustic communication, the DCT-OFDM approach is introduced for improved BER performance [25]. The performance comparison in terms of BER for underwater acoustic

communication utilizing OFDM is examined in this paper. The remaining of the paper is organized as follows: Section 2 describes various modes of propagation in underwater communication, Section 3 describes challenges in underwater communication, Section 4 provides an overview of the literature review, and Section 5 delves into an explanation of BER comparison. Finally, section 6 concludes and outlines the future scope.

2. Different Modes in Underwater Communication System

Underwater wireless communication can be done in three different ways. These include electromagnetic (EM), optical, and acoustic waves. Every wave has pros and cons in terms of how it can communicate.

ElectroMagnetic Waves

EM waves can travel at radio frequencies for short-distance communication. They are quickly dampened, but they can transmit large amounts of data. Permittivity, permeability, volume charge density, and conductivity all influence the velocity of propagation, which is primarily determined by the frequency of operation utilized in underwater communication. The signal's attenuation increases with operating frequency. EM waves may communicate across a distance of 10 meters [2].

Optical Waves

Despite their narrow wavelength (between 390 and 700 nm), optical waves have a high bandwidth, which makes them vulnerable to absorption, temperature changes, scattering, and line-of-sight communication. The fundamental difference between RF and optical technologies is their communication distance. The medium behavior when the communication distance has risen from 10m in EM waves to 100m for optical and water medium is observed as dielectric for optical and conductor for RF. Still, their velocity of propagation is the same. [2].

Acoustic Waves

With acoustic waves serving as the primary transmission means, underwater communication may transport data at speeds of hundreds of kilobits per second over short distances (a few meters) and tens of kilobits per second over longer distances (kilometers). Table 1 classifies RF, Optical, and Acoustic wave communication.

Table 1: comparison of various underwater communication technologies[2].

Parameter	RF	Optical	Acoustic
Attenuation	0.1-4dB/m	11dB/m	(3.5-5dB/m)
Data rate	Mbps	Gbps	Kbps
Bandwidth	MHz	10-150 MHz	(1 -100) KHz
Frequency Range	30-300Hz	10^{12} - 10^{15} Hz	10-15 KHz
Propagation speed(m/s)	2.25×10^8	Almost the same as the RF	1500
Distsance	< 10 m	< 100m	< 20Km
Factors affecting channel	Conductivity, Permittivity	Turbidity, scattering, absorption	Absorption, scattering, temperature, pressure, and salinity of water
Latency	Moderate	Low	High
Size of Antenna	0.5m	0.1m	0.1m

3. Challenges in Underwater Communications

Many problems exist in underwater communication, including delay, bit error rate, the Doppler Effect, multipath propagation and ambient noise. When compared to terrestrial transmission, underwater communication has a long delay. The Doppler effect will decide how well a communication works. When the multiple versions of the signals are received at receiver, they create inter-symbol interference. The main elements influencing underwater communication with a high BER are thermal and ambient noise, making dependable data transfer in these settings even more difficult [2].

4. Literature Review

Dev Pratap Singh and Deepak Batham [1] investigate the increased interest in the aquatic environment for various applications. The difficulties in commercial, military, and business applications are also covered. It provides an analogy between optical, electromagnetic, and acoustic.

Suresh Kumar and Chanderkant Vats [2] discuss the existing demand, problems, and applications for underwater communications. Additionally, they go over the three different underwater communication techniques—acoustic, optical, and radio frequency—and contrast them based on several variables, such as latency, speed, bandwidth, operating frequency, attenuation, and propagation distance.

Shailee Soni, Kirtivardhan Jha *et.al*[3] describe the acoustic channel utilized for underwater audio communication. It also covers the elements that

influence acoustic communication. It analyzes the features of acoustic channels for seawater and other underwater acoustic channels and the characteristics of each model's past work.

Pranitha and Anjaneyulu [4] present modulation schemes used in long-distance UWA communication, such as Binary Phase Shift Keying (BPSK), QPSK, and 4-QAM.

According to Tri Budi Santoso, Wirawan *et.al* [5], the transmission of images over the underwater acoustic channel is explained. Additionally, it discusses forward error correction hamming with OFDM and BPSK, which has good BER performance.

Pallavi Suryawanshi, Vaishali Sonone *et.al*[6] describe an OFDM approach for application in an underwater channel environment. Two strategies are discussed: the waterline technique and the multimedia system methodology. The multimedia technique outperforms the other in terms of power and error protection.

Van Duc Nguyen, Hoai Linh Nguyen Thi *et.al* [7] present the Non-Uniform FFT and Doppler Frequency Compensation Matrix (DFCM-NFFT), which combines channel estimation and ICI reduction for underwater audio communication via OFDM. The suggested approach can enhance BER performance by compensating for the Doppler shift.

According to Peng Chen, Yue Rong *et.al* [8], impulsive noise in the underwater acoustic channel can lessen UWA OFDM's efficacy. Two new approaches are suggested to lower the bit error rate: joint channel estimation and impulsive noise mitigation.

T. C. Yang and Wen-Bin Yang [9] explain the spread spectrum signals in direct sequence and evaluate performance using the BER.

Zhang Lan, Xu Xiaomei *et.al*[10] discuss underwater acoustic communication with multicarrier modulation, such as OFDM. IRA is proposed as a channel coding to improve the effectiveness of an OFDM-based system for underwater communication. These methods can enhance BER performance.

Prashant Kumar, Vinay Kumar Trivedi *et.al*[11] describe the operation of a Differentially encoded Quadrature Phase Shift Keying (DQPSK) modulated OFDM for underwater audio communication. As a result, the design is straightforward and dependable, and the phase difference stays constant, improving BER performance.

Rajashri Khanai, Dattaprasad A. Torse [12] analyze the performance of underwater acoustic communication using BPSK, QPSK, and QAM. IDMA-OFDM-MIMO techniques, as well as random interleaved and turbo code, are presented to increase BER performance.

The OFDM system used in underwater sound communication to solve problems with transmit beam creation is described by Diego A. Cuji, Milica Stojanovic [13]. Different detection approaches are addressed at the receiver, including differential and coherent detection. The essay also explores the angle tracking method to reduce complexity in mobile systems.

Shadrach Kukuchuku, Dikio C Idoniboyeobu *et.al*[14] Explain the Optimized OFDM, which reduces the number of subcarriers in the OFDM to provide improved BER performance compared to the unoptimized version.

Zeyad A.H. Qasem, Hussein A. Leftah *et.al*[15] outline the main challenges in multicarrier underwater audio transmission architecture. Furthermore, a unique approach, such as spread spectrum, orthogonal frequency division modulation, and precoded index modulation, is proposed to improve transmission efficiency and reduce the Peak Average Power Ratio (PAPR), resulting in a more dependable communication system.

Prashant Kumar and Preetam Kumar [16] describe a spread OFDM technique for underwater acoustic communication that combines the concepts of spread spectrum and multicarrier modulation, as well as Carrier Interferometry (CI), DFT, DCT, and Walsh

Hadamard codes. The proposed solutions reduce the peak-to-average power ratio and the bit error rate.

Prashant Kumar and Preetam Kumar describe the performance of underwater acoustic communication utilizing OFDM for two distinct situations, DCT and DFT, [17]. The DCT-based approach outperforms the other one regarding BER performance and is less complex.

Yuning Widiarti, Wirawan *et.al* discuss the uses and difficulties of underwater audio communication [18]. They also address issues such as multipath fading, which OFDM can lessen. It also explores time reversal using temporal and spatial focal characteristics to lessen channel fading and inter-symbol interference.

Xilin Cheng, Miaowen Wen *et.al*[19] discuss the UWA OFDM, which suffers from (ICI), and how an efficient mirror mapping-based technique can reduce ICI.

Prashant Kumar and Preetam Kumar [20] compare the efficiency of underwater audio communication using several SOFDM approaches.

Preetam Kumar, Vijay Mukati *et.al*[21] provides the effectiveness of Spread OFDM with space-frequency block coding for underwater audio communication.

Mohammad A Bocus, Dimitris Agrafiotis *et.al*[22] outline the NOMA scheme, which can be used with OFDM and FBMC. When it comes to BER, FBMC performs better than the other. OFDM BER performance ZS is determined by the type of modulation utilized.

Mohamed Elmahallawy, S. Elagooz1[23] Underwater acoustic communication uses a variant of OFDM-FFT called the Fast Walsh-Hadamard transform (FWHT) instead of the Fast Fourier Transform (FFT). The Low Density Parity Check (LDPC) is employed for encoding and decoding.

Anwar, Sheraz *et.al*[24] describe the Non-OFDM methods for designing new underwater acoustic communication receivers. Non-OFDM approaches use more closely packed subcarriers, resulting in improved spectral efficiency.

Prashant Kumar and Preetham Kumar [25] describe the DCT-OFDM technology for underwater acoustic communication, which has a smaller implementation area, faster computational speed, and higher PAPR, resulting in superior BER.

Jianguo Huang, Jing Sun *et.al*[26] discusses OFDM's performance against multipath interference, frequency

selective fading, and spectral efficiency. Displays varying data rates at various separations.

Based on the literature survey, it can be observed that the BER can be decreased using modulation techniques like QPSK, DSSS, and OQAM, when compared to OFDM alone using BPSK. Further BER can be improved by using Filter Bank Multicarrier(FBMC) and Generalized Frequency Division Multiplexing(GFDM). FBMC decreases the out-of-band emission, thereby decreasing interference with adjacent channels and

resulting in improved BER. GFDM reduces inter-symbol interference thereby improving BER.

Table 2 includes a BER comparison of OFDM using various modulation techniques. This table provides the BER range for a given range of SNR respectively. Time reversal spatial and temporal modulations perform the worst in terms of BER for 16QAM, while DSS and IRA approaches perform the best among the modulations given in the table below.

Table 2: Performance Comparison of Different OFDM Modulation Techniques in Terms of BER

RRef. No	Method/ Technique	SNR (dB)	BER	Modulation
[6]	Waterline, Multimedia	8,10	3/1000	FSK
		8,10	2/1000	
[7]	NFFT, DFCM	-3 to 11	10^{-4} to 10^0	QPSK
[8]	Channel Estimation & Impulsive Noise	0 to 20	10^{-5} to 10^0	PSK or QAM
[9]	DSS for UWA	-20 to 25	10^{-6} to 10^0	BPSK
[10]	IRA with OFDM	0 to 20	10^{-6} to 10^0	QPSK
[11]	DQPSK-OFDM	0 to 20	10^{-5} to 10^{-1}	DQPSK
[12]	IDMA-OFDM-MIMO	0 to 14	0.5×10^{-3}	BPSK
[13]	Transmit beamforming	-10 to 30	10^{-5} to 10^0	8-PSK
[14]	Optimizing sub-OFDM	10	10^{-5}	QPSK
[15]	Precoded IM-OFDM	0 to 30	10^{-4} to 10^0	QAM
[16]	Walsh Hadamard OFDM	0 to 20	10^{-4} to 10^0	BPSK
[17]	DCT-SOFDM, DFT-SOFDM	0 to 15	10^{-5} to 10^{-1}	QPSK
[18]	Time Reversal Spatial and Temporal	8.2	10^{-3}	BPSK
		20	0	BPSK
		20	0.0034	QPSK
		20	0.53	16QAM
[19]	Effective Mirror Mapping	---	0.0172	QPSK
			0.0093	BPSK
[20]	SOFDM	10	4×10^{-2}	QPSK
[21]	SFBC-SOFDM	10	2×10^{-2}	QPSK
[22]	NOMA-OFDM, NOMA-FBMC	0 to 25 Eb/No	10^{-4} to 10^0	OQAM

5. BER Comparison

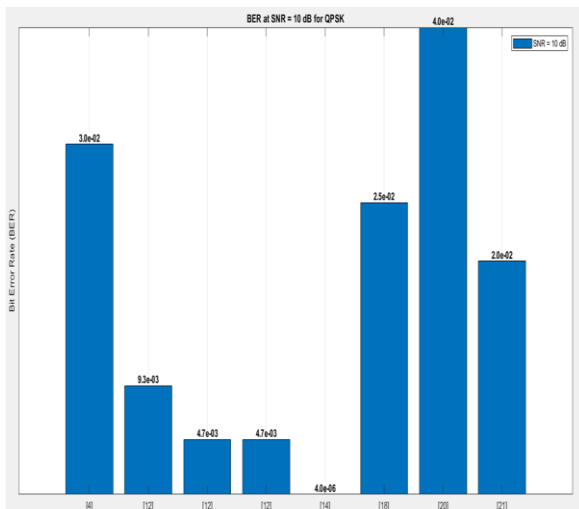


Fig 1: Comparison of BER with fixed SNR using the QPSK modulation technique

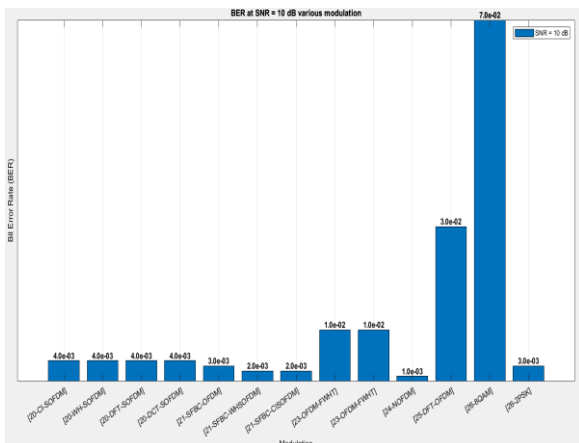


Fig 2: Comparison of BER with fixed SNR using different modulation techniques

Figure 1 shows a BER performance comparison for a fixed SNR of 10 dB using QPSK modulation. Based on the BER comparison, Optimizing the number of sub OFDM blocks approach [14] has improved BER, and the Spread OFDM with a transmit diversity approach [20] has minimal BER performance.

Figure 2 shows the BER performance comparison for a constant SNR of 10 dB with various modulation techniques. Based on the BER comparison, UWA-NOFDM technique [24] has improved BER and OFDM with 8QAM [26] has minimal BER performance

6. Conclusion and Future Scope

Underwater communication serves as a channel for connecting offshore and underwater devices. Underwater communication uses a variety of modes, including Electromagnetic, Optical, and Acoustic waves,

to transfer information below the water surface. Due to their low attenuation, good speech, and data quality, Underwater acoustic communication is widely used among those methods. Although it is susceptible to temperature and salinity changes, it is also helpful for long-distance communication. As a result, this work examines a survey of BER comparison for UWA communications employing OFDM with various modulation schemes. The future scope of this work is to improve BER further by decreasing the intersymbol interference by using Generalized Frequency Division Multiplexing (GFDM) and decreasing out of band emission using the multicarrier modulation technique like Filter Bank Multi Carrier (FBMC).

References

- [1] D. P. Singh, and D. Batham, "A review of underwater communication systems," *International Journal of Engineering Development and Research*, vol. 10, pp.100-104, 2022.
- [2] K. Suresh, and C. Vatsb, "Underwater communication: A detailed review," *CEUR Workshop Proceedings*, Chennai, vol. 2889, pp. 8, 2021.
- [3] S. Soni, K. Jha, and S. Changlani, "An extensive review on underwater acoustic channel," *International Journal of Scientific Progress and Research (IJSPR)*, vol. 1, pp. 27-31 2014.
- [4] B. Pranitha, and L. Anjaneyulu. "Analysis of underwater acoustic communication system using equalization technique for ISI reduction," *International Conference on Computational Intelligence and Data Science*, Kalavakkam, Tamilnadu, vol. 167, pp. 1128-1138, 2020.
- [5] Santoso, T. Budi, and G. Hendrantoro. "Image transmission with OFDM technique in underwater acoustic environment," *Proceedings of 7th International Conference on Telecommunication Systems, Services, and Applications (TSSA)*. Denpasar-Bali, Indonesia, pp. 37-41, IEEE, 2012.
- [6] Suryawanshi, Pallavi, V. Sonone, and A. Jadhav. "Underwater communication by using OFDM system," *International Journal of Scientific and Research Publications*, vol. 3, pp. 1-5, 2013.
- [7] Thi, H. L. Nguyen, Q. K. Nguyen, and T. H. Nguyen. "Low complexity non-uniform FFT for doppler compensation in OFDM-based underwater acoustic communication systems," *IEEE Access*, vol. 10, pp. 82788-82798, 2022.
- [8] Chen, Y. Rong, S. Nordholm, Z. He, and A. J. Duncan. "Joint channel estimation and impulsive noise mitigation in underwater acoustic OFDM communication systems," *IEEE Transactions on*

- Wireless Communications*, vol. 16, pp. 6165-6178, 2017.
- [9] T. C. Yang, and W. B. Yang. "Performance analysis of direct-sequence spread-spectrum underwater acoustic communications with low signal-to-noise-ratio input signals," *The Journal of the Acoustical Society of America*. vol. 123, pp. 842-855, 2008.
 - [10] Zhang, Lan, et al. "Performance analysis of IRA codes for underwater acoustic OFDM communication system," *Proceedings of 5th International Conference on Wireless Communications, Networking and Mobile Computing*. Beijing, China, pp. 1-4, IEEE, 2009.
 - [11] P. Kumar, V. K. Trivedi, and P. Kumar. "Performance evaluation of DQPSK OFDM for underwater acoustic communications," *IEEE Underwater Technology (UT)*. Chennai, pp. 1-6, 2015.
 - [12] K. Rajashri, and D. Torse. "Performance analysis of underwater acoustic communication using IDMA-OFDM-MIMO with Reed Solomon and turbo code" *International Journal of Computer Network and Information Security*., vol. 10, pp. 41-46, 2018.
 - [13] D. A. Cuji, and M. Stojanovic. "Transmit beamforming for underwater acoustic OFDM systems," *IEEE Journal of Oceanic Engineering*. vol. 1 pp.1-18, 2023.
 - [14] S. Kukuchuku, et al. "Improved underwater wireless communication system using OFDM technique," *American Journal of Engineering Research*., vol. 7, pp. 82-95, 2018.
 - [15] Z. A. H. Qasem, et al. "Precoded IM-OFDM-SS for underwater acoustic communication," *Wireless Communications and Mobile Computing (Online)*. pp. 1-12, 2022.
 - [16] P. Kumar, and Preetam Kumar. "Performance evaluation of modified OFDM for underwater communications," *Proceedings of IEEE International Conference on Communications Workshops (ICC)*., Hungary, pp.967-971, 2013
 - [17] Kumar, Prashant, and P. Kumar. "Performance evaluation of DFT-spread OFDM and DCT-spread OFDM for underwater acoustic communication," *Proceedings of IEEE Vehicular Technology Conference (VTC Fall)*., Quebec City, QC, Canada, pp. 1-5, 2012.
 - [18] Y. Widiarti, Wiraman, Suwadi. "Image transmission with joint time reversal and OFDM in underwater acoustic environment," *Journal of Physics: Conference Series, IOP Publishing*, vol. 1179, pp. 1-7, 2019.
 - [19] X. Cheng, et al. "Effective self-cancellation of intercarrier interference for OFDM underwater acoustic communications," *Proceedings of the 8th International Conference on Underwater Networks & Systems*. Kaohsiung, Taiwan, pp.1-5, 2013.
 - [20] Kumar, Prashant, and Preetam Kumar. "A comparative study of spread OFDM with transmit diversity for underwater acoustic communications." *Wireless Personal Communications* vol.83, pp. 69-86, 2015.
 - [21] Kumar, Prashant, Vijay Mukati, and Preetam Kumar. "Performance evaluation of SFBC-SOFDM for underwater acoustic channels." *OCEANS-TAIPEI. IEEE*, 2014.
 - [22] M. J. Bocus, D. Agrafiotis, and A. Doufexi. "Non-orthogonal multiple access (NOMA) for underwater acoustic communication," *Proceedings of IEEE 88th Vehicular Technology Conference (VTC-Fall)*. Chicago, pp. 1-5, 2018.
 - [23] El-Mahallawy, Mohamed, Adly S. TagEldien, and Salah S. Elagooz. "Performance enhancement of underwater acoustic OFDM communication systems." *Wireless Personal Communications*., vol 108, pp. 2047-2057, 2019.
 - [24] Anwar, Sheraz, et al. "A novel receiver design of nonorthogonal FDM systems in underwater acoustics communication." *IEEE Systems Journal*, vol. 14.3 pp.3875-3884,2019.
 - [25] Kumar, Prashant, and Preetam Kumar. "DCT based OFDM for underwater acoustic communication." *Proceedings of IEEE sponsored 1st International Conference on Recent Advances in Information Technology (RAIT)*. pp. 170-176, 2012.
 - [26] Huang, Jianguo, et al. "High-speed underwater acoustic communication based on OFDM." *Proceedings of IEEE International symposium on microwave, antenna, propagation, and EMC technologies for Wireless Communications*., vol. 2, pp. 1135-1138, 2005.