Design and Evaluation Study of Performance of Optical Wireless Sensors Network for Achieving High Data Rate and Power Saving

https://doi.org/10.3991/ijim.v15i14.21427

Isam Aameer Ibrahim (✉)
University of Baghdad, Baghdad, Iraq
University of Thi-qar, Nasiriyah, Iraq
isam.omair1101a@ilps.uobaghdad.edu.iq

Tahreer Safa'a Mansour
University of Baghdad, Baghdad, Iraq

Abstract—This research study, examines the design and evaluates the performance of the Underwater channel of Optical Wireless Communication systems (UOWC). These systems are implemented through medium communication link ranges for the purpose to overcome absorption and scattering as well as to meet the requirements of a wide variety of optical wireless applications. There are two ways for the application of the design mentioned above. The first way is the application of the two modulation schemes of technology that is Differential Phase Shift Keying (DPSK) modulation with Direct Detection (DD) and the DPSK modulation with Coherent Detection (CD). Both modulation schemes operate on Optical Orthogonal Frequency Division Multiplexing (OFDM) with different configurations of multi-input multi-output technology (MIMO). The second way is based on a mathematical model which has been proposed for this study. This mathematical model calculates optimal beacon period (BI) and optimal listen interval (LI) to preventing the overlapping of time between the signals and the decrease in the required power. By using different types of water samples, the simulation results revealed that the best performance of the UOWC system is from link range and the receiver is more sensitive. The simulation results are as follows: BER is equal to 10-5, BI is equal to 85ms, and LI is equal to 108ms.

Keywords—Optical Wireless Communication, Power Management, Differential Phase Shift Keying, Coherent Detection, Direct Detection, Underwater channel, Orthogonal Frequency Division Multiplexing

1 Introduction

Two-thirds of our Earth is covered by water, as it is a water planet. With the rapid technological developments, the area of underwater communications has grown rapidly and extensively with a wide-range of applications in many fields such as in the military forces and commercial sectors. The applications required for underwater wireless communication include remote monitoring in offshore oil industry, pollution control in environmental systems, scientific data collection from ocean base stations, disaster detection and early warning, national safety as well as security and discovery of resources. Hence, the studies into modern underwater wireless communication technologies play a crucial role in all marine environments [1]. In particular the ocean Contrary to terrestrial wireless communication, underwater wireless network channels may be greatly affected, by a multitude of factors such as marine environment, noise, limited power, bandwidth, and difficult underwater environments. As such, the underwater wireless channel faces numerous challenges such as serious attenuation, multipath effect, frequency dispersion, limited bandwidth, and power resources. All these cause the underwater wireless channel to be one of the toughest and most complex system. The unique underwater conditions pose many new challenges that were not faced in wireless terrestrial communications. Despite these shortcomings, the demand for wireless underwater networks is on the rise especially in acoustic, optical, and RF (Radiofrequency) communications. The underwater wireless channels are much sought after for acoustics and optical due to efficient transmissions for long distance and high-bandwidth network communications in terms of size, power enabled modems and unmanned systems that are among the challenges [1]. The popularity of underwater wireless networks has caught the attention of researchers, not only in the education field but also in the military forces and manufacturing sectors due to the potentials in transmissions in advanced underwater communications. In recent years, much research work has been implemented for the underwater wireless network, but problems begin to surface with further development in the study of this system, especially due to the challenges posed in the study of acoustic and optical wireless channels [2]. There are three possible approaches in underwater communications, namely acoustic which is the transmission of sound waves, Radiofrequency transmission through electromagnetic waves, and Optical communication which is transmission via optical carriers [3]. Each of these approaches is with its benefits and shortcomings. Acoustic propagation underwater is affected by high noise level, high latency, path loss, multi-path, high bit error data rate which is equivalent to 10^{-2} - 10^{-5}, and bandwidth restricted depending on range and frequency [3]. Furthermore, acoustic communication is not the best choice for underwater transmission particularly for applications that require high data rates, multipath, and real-time activity. Likewise, RF carriers, suffer from high underwater attenuation and require large antennas and high transmission power at low frequencies, which are not feasible underwater. On the contrary, Optical carriers include electromagnetic waves of wavelength between 400 nm (blue light) and 700 nm (red light). Because of its short wavelength, high frequency, and high speed, these optical waves are capable of communicating at an extremely high data rate (up to 1Gbps) [4]. These short optical waves are suitable for use as wireless communication carriers, despite, strong water absorption and strong backscatter of suspended particles in the optical frequency band. Therefore, these optical waves that offer high data rate, and high bandwidth, are a feasible for underwater optical communications [5].

2 Literature Review

In the last few decades, many research studies focused on UOWC systems to solve the problems of underwater propagation. The UOWC system can be considered as an energy-efficient and cost-effective solution for high data rates and low latency [6]. However, when the light beams are absorbed and scattered, they faced the multipath effects in underwater propagation. This often leads to signal deformation in the Shape of an Inter- Symbol Interference (ISI) and decline in the total performance of the UOWC system [7]. While OFDM-MIMO demonstrates the benefits of wireless communication in the air, it can be considered a possible method for utilization in the underwater wireless communication system [7]. As for UOWC system it offers an attractive and a promising way to address the limitation of the traditional underwater wireless sensor network system. Although optical carriers can be utilized for accomplishing high data rate communications in Gigabit per second (Gbps), they suffer from scattering and absorption in water [8]. Previews of research studies on UOWC and of some technologies used for underwater applications such as design and evaluation of underwater OWC systems using 16-QAM-OFDM and 256-QAM-OFDM modulation as well as green LD with PIN detector to achieve BER that equals to 2.98 $\times 10^{-3}$ under clear water have shown that these wireless systems can operate efficiently for up to just 2 meters [9]. The multi-input and multi output OFDM for the underwater OWC system is fixed with blue LED and PIN photodetector of up to a depth of 2 meters in water channel to achieve BER equal to 2.6 $\times 10^{-3}$ and with unaccepted delay [10]. An Underwater OWC based on an LED system that utilizes OFDM under turbid water in the range of 10m and a depth of 3m to achieve BER of less than the FEC threshold which is equal to 10^{-3} [11]. An underwater OWC system with the following features has been low latency by multiplexes, a few optical carrier signals and an energy-efficient has been used achieved by using an underwater OWC system. Absorption and scattering which are faced the light beam that is propagated underwater is decreased and channel capacity is increased.

3 Design DPSK-DD-Optical OFDM

This section presents a description of the design of DPSK-DD with optical OFDM.The design is realized using optiwave software, that has played a pivotal role in the provision of a huge number of optical and wireless components for building and implementing a complete optical network scheme with an access network. In this design, the pseudorandom binary sequence has been used to determine the length of the input and the data sequence. Also, it is set to the regular period which is equal to 2^{15}-1 in the transmitter part. The application of a bit sequence into the M-DPSK encoder has generated M-Array with transmtremative ability. The M-Array sequence can be transformed into information symbols by changing the M-Array code from serial to parallel. Each of the information symbol includes multiple bits from M-array coding. Meanwhile, the intensity Modulation /Direct Detection (IM/DD) feeds on the output of the RF signal. For the purpose of this research Mach–Zehnder modulators

(MZMs)are used with a laser diode (LD) of 450nm to convert the OFDM signal from the RF domain to the optical domain. The power equipped for the use of LD is fixed at 20dBm. Finally, the functionality of the optical signal from the Lithium Niobate Mach-Zehnder Modulator (LiNb-MZM) is transmitted through the underwater channel.

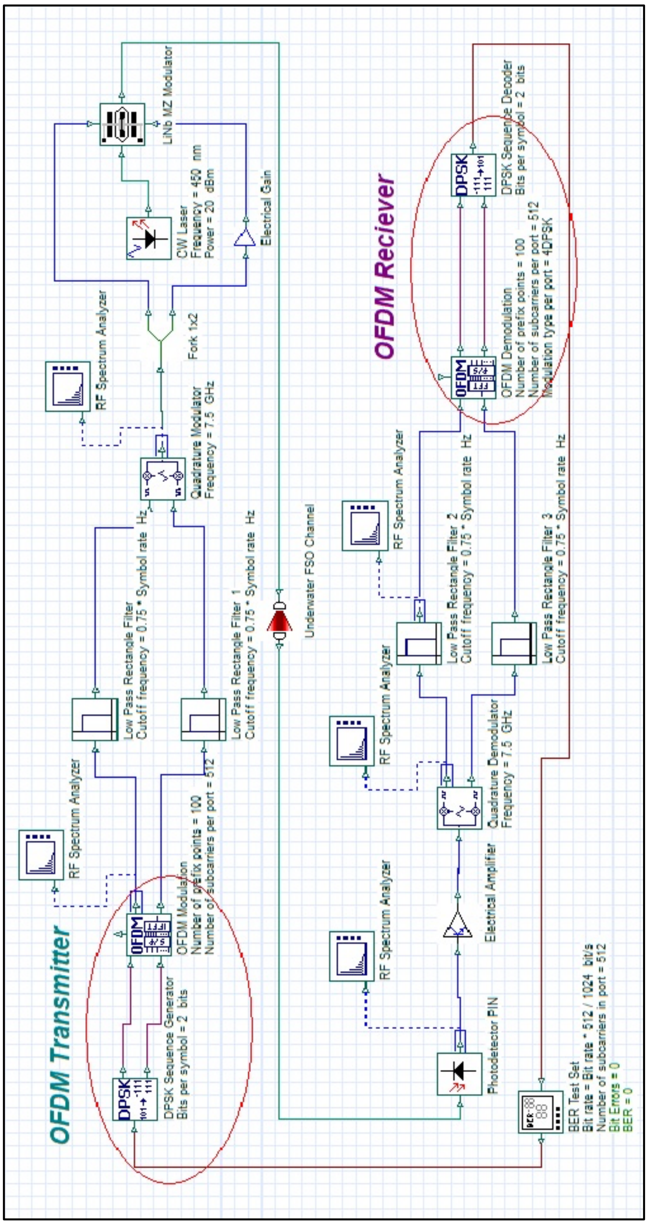


Fig. 1. Design of DPSK-DD with the optical OFDM system

Table 1 shows the specifications of the main parameters of the proposed DD-Optical OFDM System that can be used to transmit information signals from the transmitter section to the receiver section.

Table 1. Specification parameters of DD-OFDM Optical.

Parameters	Values	Units
Data Transmission Rate (DTR)	10	Gbps
Modulation Scheme	DPSK	Low PAPR
LD wavelength	450	nm
OFDM subcarrier size	512	FFT/IFFS
Optical channel	Water	clean, turbid
Transmitted power	20	dBm
Receiver aperture	50/75	mm
Photodetector	PIN	Low noise
Dark current	10	nA
Basic Transmission Rate	2	Mbps

4 Mathematics of MIMO in Optical Communication

The optical signal suffers from high attenuation in underwater communications because of the physical and chemical characteristics of water [9-10]. This setback has motivated many researchers to develop techniques that may adapt to such hostile environment. The use of MIMO technique has shown significant increase in channel capacity, which means the transmission rate is increased because it uses more than one antenna element [11]. Fig. 2 illustrates the MIMO channel technique. It attempts to explain the communication system that includes multi-transmitter waves which start from (T_{X1}……T_{XNT}) respectively. These waves are sent to the receiver elements (R_{X1}....... R_{XNT}). The incoming waves are merged coherently by the receiver element which is indicated by (y_1.........y_N) respectively. The received signal is assigned according to the traffic pattern of each station as denoted by Tx_q q = 1, ….., N_R [12-13].

$$y_q = \sum_{j=1}^{N_T} h_{qp} \cdot x_p + b_q; q = 1,2,\ldots.,N_R \tag{1}$$

The flat fading of the MIMO channel technique is described by the input and output relationship.

$$y = H \cdot x + b \tag{2}$$

where H is defined by ($N_R \times N_T$) ,as a complex channel matrix. The explanation is as below:

$$H = \begin{pmatrix} h_{11} & h_{12} & \cdots & h_{1NT} \\ h_{21} & h_{22} & \cdots & h_{2NT} \\ \vdots & \vdots & \ddots & \vdots \\ h_{NR1} & h_{NR2} & \cdots & h_{NRNT} \end{pmatrix} \tag{3}$$

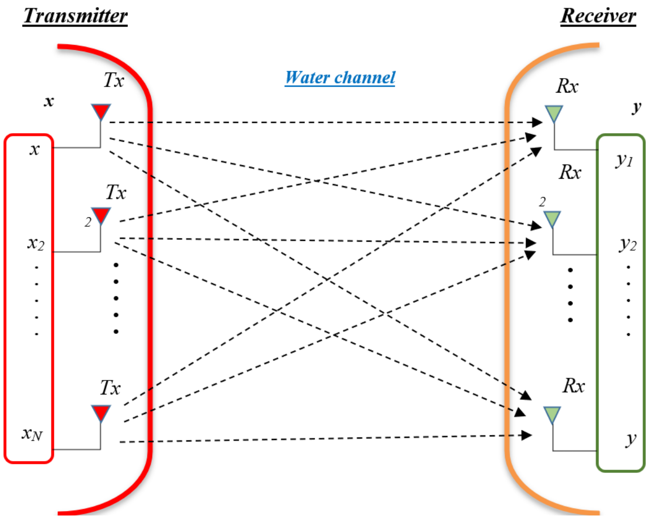


Fig. 2. MIMO channel technique [13]

Where $j = 1, . . . , N_T$; $q = 1, . . . , N_R$ is the gain of complex channel which is linked to the transmitter signals Tx_j to receive the elements. Rx_q, $x = [x_1, . . . , x_{NT}]^T$ is $(N_T \times 1)$, the vector of complex transmitted signal, $y = [y_1, . . . , y_{NR}]^T$ is the $(N_R \times 1)$ vector of complex received signal and $b = [b_1, . . . , b_{NR}]^T$ is the $(N_R \times 1)$ vector of additive complex noise signal.

5 Design DPSK-CD-Optical OFDM

Figure 3 illustrates the proposed design DPSK-CD-Optical OFDM which has been completed using Optiwave software. The architectural design of the DPSK-CD-Optical OFDM system is similar to that of DPSK-DD-Optical OFDM but with two additional functions, namely RF to optical Upconverter (RTO) at the transmitter and optical to RF Downconverter (OTR) at the receiver. The OTR function consists of Coherent Detection (CD) and it utilizes balanced noise detectors. The length of the input data sequence is set to 2^{15}-1 and it is built with a PRBS in the transmitter for production of a bit sequence which is applied into the M-DPSK encoder to generate M-Array sequences. The output of the encoder is linked to an OFDM modulator with subcarriers that amount to 1024 at 2048 FFT points. The resulting signal from the OFDM modulator is then fed as in-phase (I) and quadrature (Q) to the RTO unit. The RTO function consists of an X-coupler, two Mach-Zehnder modulators, and an optical combination unit. The output ports feed to the MZMs, while the (I) and (Q) carry components on the first input port of the coupling coupler

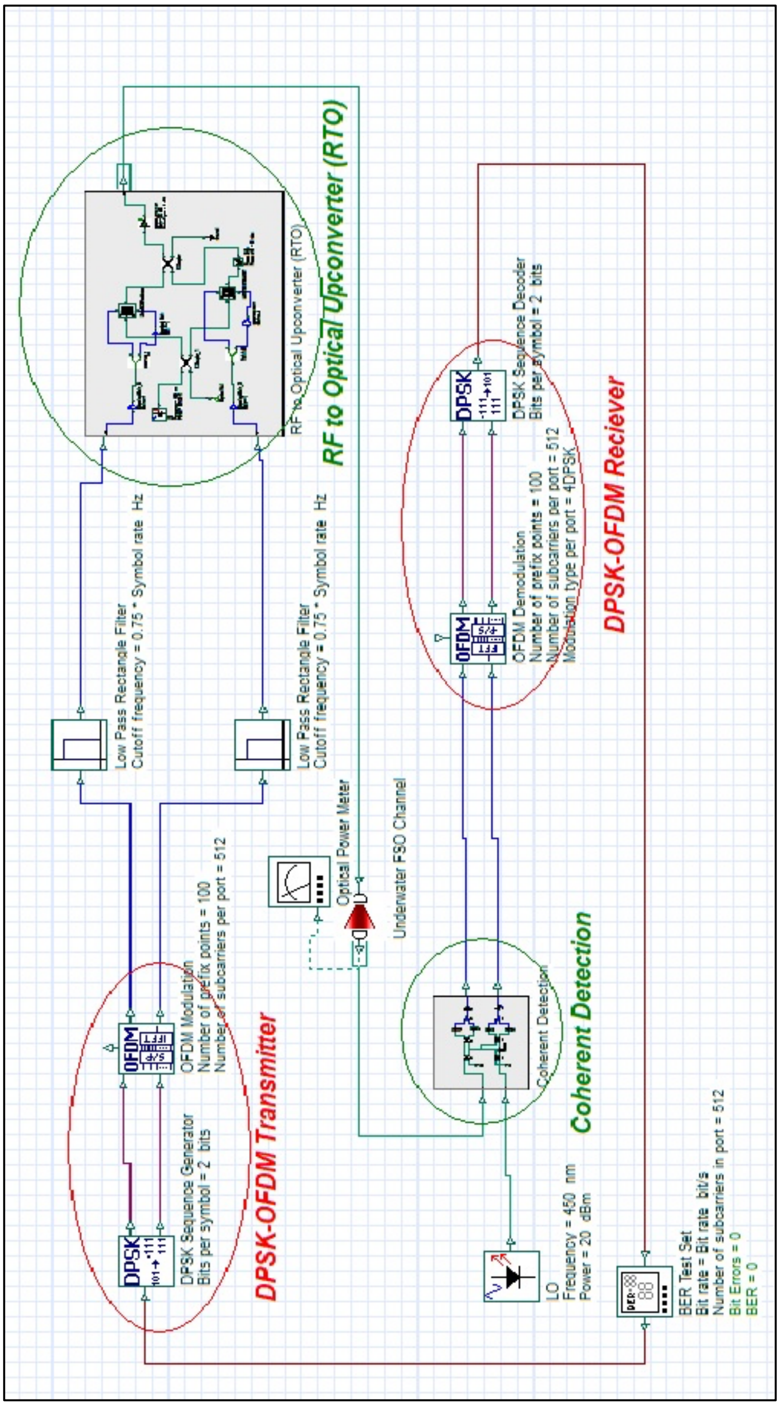


Fig. 3. Design of DPSK- DD with optical OFDM system

Table 2. shows the main parameters of the DPSK-CD-Optical OFDM system.

Parameters	Values	Units
Data Transmission Rate (DTR)	10	Gbps
Modulation Scheme	DPSK	Low PAPR
LD wavelength	450	nm
OFDM subcarrier size	512	FFT/IFFS
Optical channel	Water	clean, turbid
Transmitted power	20	dBm
Receiver aperture	50/75	mm
Photodetector	PIN	Low noise
Dark current	10	nA
Coherent detection type	Balanced Quadrature Coherent Receiver	Detect any optical modulation
Basic Transmission Rate (BTR)	2	Mbps

6 Mathematical Model of Power Saving Mode

The purpose of the implementation of the proposed analysis is to determine a precise average ratio of the time when the station remains in the doze mode. This approach is aimed at reducing the inefficiency of two factors found the Power Saving Mode (PSM) mechanism, namely channel contention, and prevention of frequent waking up of stations. In this proposed scheme, there are two random variables namely; interframe arrival time and packet frame size. The interframe arrival time can be expressed in three types of distributions; deterministic (DET), uniform (UNI), and exponential (EXP). Meanwhile, the size of the packet frame distribution is either uniform or deterministic in distribution. For an energy-saving scheme to work, the network must not be in a state of heavy load. This is because the PSM mechanism operates optimally when the network utilization (ρ) is equal to or less than 30% [14-18]. Therefore, in this research analysis, the benchmark of the utilization value must be equal to or less than 30% for every element. As such, the calculation of the utilization value is based on the formula of utilization as below.

$$\mathrm{\rho} = \mathrm{S} \times \sum_{\mathrm{J}=1}^{\mathrm{C}} \frac{1}{\mathrm{U}} \tag{4}$$

Where S is the communication time with consideration of the actual transmission time from the optical channel to the element located at the receiver and to the Power Save (PS-POLL) frame, with acknowledgment of the frame from the element to the Optical Wireless Channel (OWC) that is free of channel contention. The value of the communication time must be higher than the value of actual transmission between the optical channel and the elements located at the receiver. This is because the PSM mechanism has sleeping periods and the presence of buffered packet frames at the optical channel which need more control during the sending of packet frames to the elements. By using the PSM mechanism it avoids packet drop and channel contention both of them consume more energy.

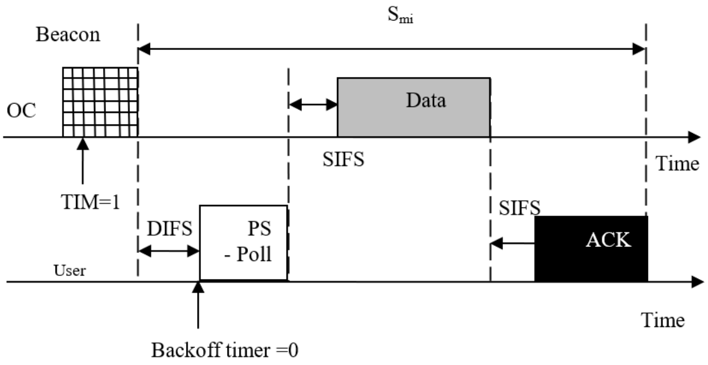


Fig. 4. The shortest communication time of receiving one packet frame

Figure 4 shows the shortest communication time for the retrieval of one data frame from an OWC to the element as well as the transmission time of three frames. After receiving one beacon frame, the PSM-enabled user must wait for a short period of time for the Distribution Coordinate Function Interframe Space (DIFS) to buffer the packet frames before sending the PS-POLL frame to the OWC. Then, the station sends out PS-POLL frames to the OWC after waiting for a random backoff timer that changes from (0) to the current contention window (CW). The OWC responds to the PS-POLL frame immediately by transmitting the packet frames after sending the shortest period namely; Short Interframe Space (SIFS). Only when, the PSM-enabled user has received this packet frame successfully, the PSM-enabled station performs the task of sending the ACK frame to the OWC after the SIFS time is released from the same station to the OC [18-21]. Based on the Distribution Coordinate Function (DCF) [20], the formula for the calculation of the communication time is as follows:

$$\text{Sact} = \frac{\text{PDS}}{\text{DTR}} + \frac{\text{PFS}}{\text{BTR}} + \frac{\text{ACK}}{\text{BTR}} + \text{CW} + \text{DIFS} + 3\text{SIFS} = 1.139\ \mu\text{s} \tag{5}$$

7 Results and Discussion

This research project has incorporated the use of a commercial software, OptisystemTM for the simulation and analysis of the UOWC systems. The performance of the UOWC system is carried out using three main water types and link ranges. Table 3 lists α(λ)J as the absorption coefficient, β(λ)J as the scattering coefficient, and λ as the wavelength. The standard values for the coefficients (c(λ), α(λ), β(λ)) have taken into consideration the three major water types with extinction values. The highest concentration of dissolved substances is found in the turbid harbor water, which seriously reduces light propagation [22]. In this research, all the critical factors that have been mentioned earlier are taken into account for the calculation of the performance of UOWC systems according to receiver sensing and link range.

Table 3. Standard values of extinction, coefficients absorption and scattering [22-28]

Water Type	$\alpha(\lambda)$ (m^{-1})	$\beta(\lambda)$ (m^{-1})	$c(\lambda)$ (m^{-1})
Pure Water	0.053	0.003	0.056
Clear water	0.114	0.037	0.151
Coastal Water	0.179	0.220	0.399
Turbid Water	0.366	1.829	2.195

Figure 5 shows BER versus link range of DPSK-DD- Optical OFDM under clear water. The achieved distance equals 133m and BER is at 2.45×10^{-5}.

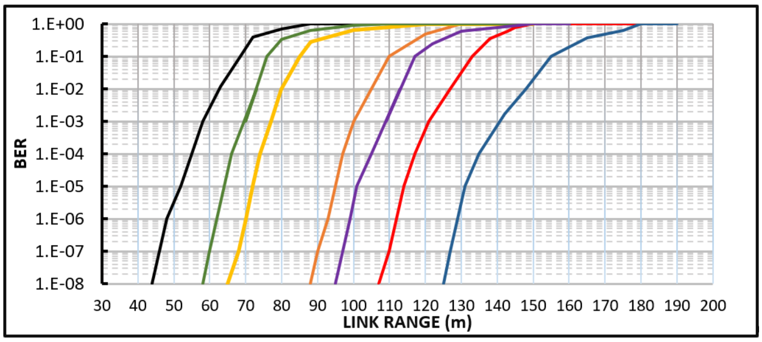


Fig. 5. Under clear water BER vs. Link Range with different MIMO configurations

Figure 6 illustrates BER versus the link range of DPSK-DD- Optical OFDM in coastal water. The achieved link distance equals 32m and BER is at 3.5×10^{-5}.

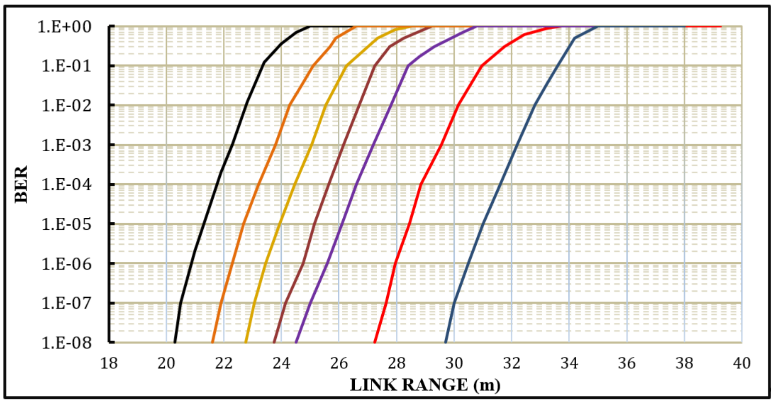


Fig. 6. BER vs. Link Range with different MIMO configurations in coastal water.

Figure 7 shows BER versus link range of DPSK–DD-Optical OFDM in turbid water. The achieved link distance equals 12m and BER is at 3.9×10^{-5}.

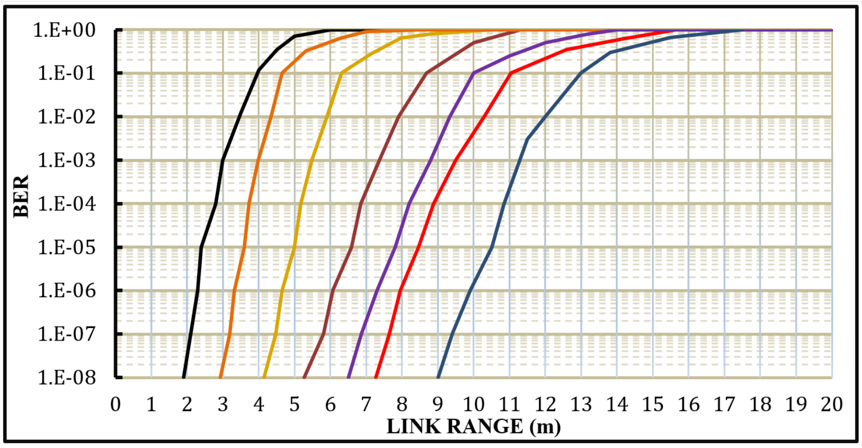


Fig. 7. BER vs. Link Range at different MIMO configurations under turbid water.

Figure 8 illustrates BER versus link range of DPSK-CD - Optical OFDM under clear water. The achieved link distance equals 157m and BER is at 3.5×10^{-5}.

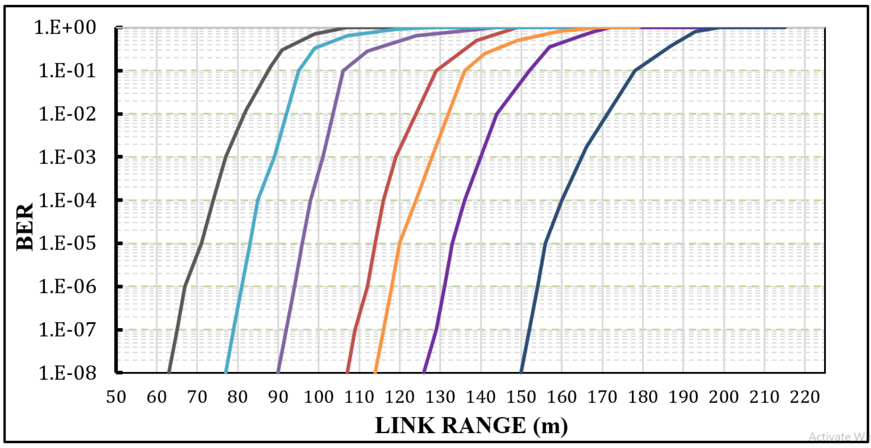


Fig. 8. BER vs. Link Range with different MIMO configurations under clear water.

Figure 9 shows BER versus link range of DPSK-CD-Optical OFDM in coastal water. The achieved link distance equals 40m and BER is at 4.5×10^{-5}.

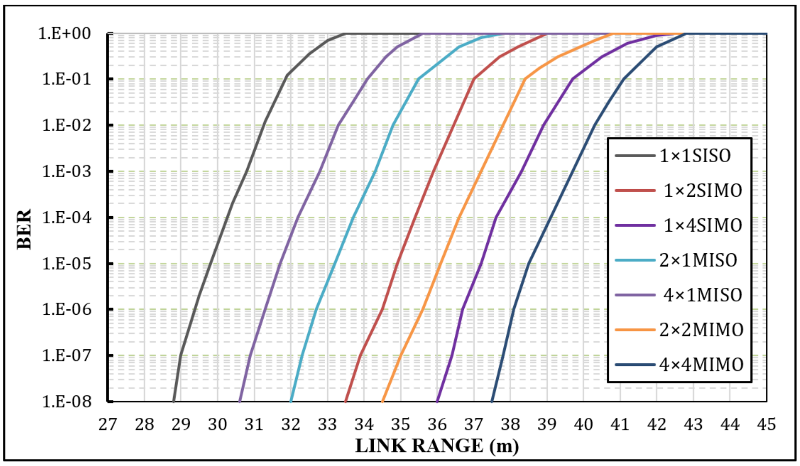


Fig. 9. BER vs. Link Range with different MIMO configurations under coastal water

Figure 10 illustrates BER versus link range of DPSK-CD- Optical OFDM in turbid water. The achieved link distance equals 12.5m and BER is at 2×10-5.

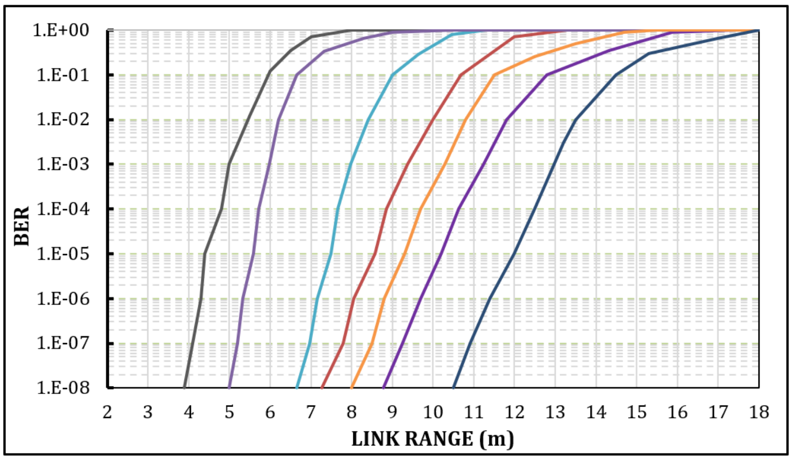


Fig. 10.BER vs. Link Range at different MIMO configurations under turbid water

Figure 11 illustrates the effect of input of power on system performance of BER for diagrams DPSK–CD-Optical OFDM and DPSK-DD-Optical OFDM under different types of waters. The results show that BER value decreases with increase in input of power.

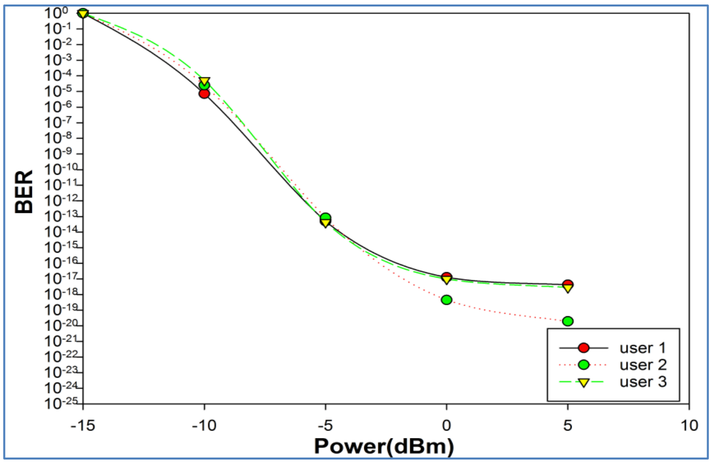


Fig. 11.BER versus input power under different types of water

Figure 12 indicates the performance of Q-factor versus distance of pure water. The results clearly shows that the Q-factor value increase when the distance of pure water is increased.

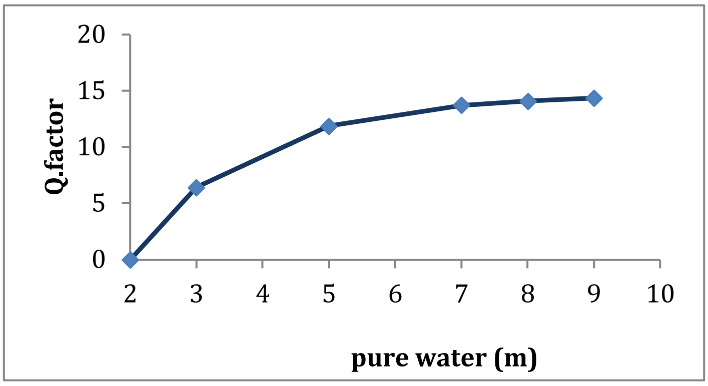
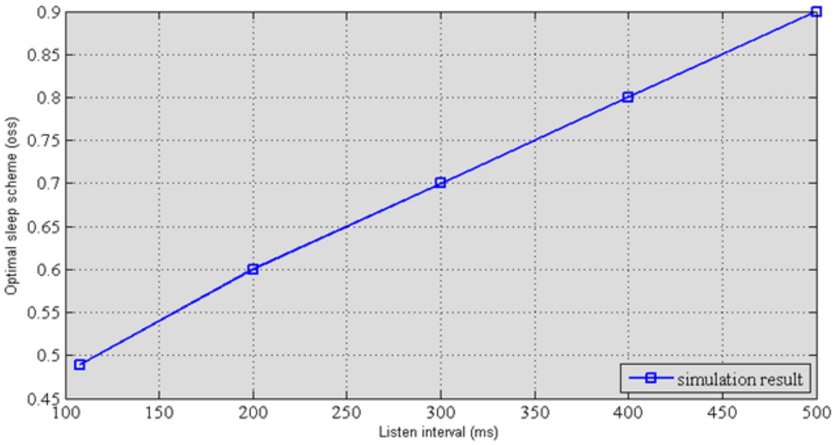


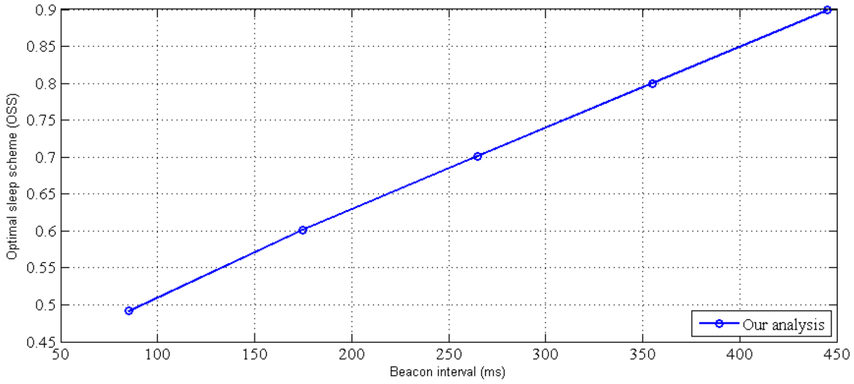
Fig. 12. Curve between Q. factor and pure water distance.

The optimal beacon interval (BI) and listen interval (LI) are calculated using Microsoft Visual C++ 2010 and the least common multiple. The calculation between the optical wireless channel (OWC) and the users for the new scheme, Optimal Sleep Scheme (OSS) is 85ms for BI and 108ms for LI.

The study of the performance of the UOWC system is carried out using different types of water and link ranges. The main modulation format used in the simulation is DPSK. This modulation records strong against water turbulence, weak signals, and gives low PAPR. The performance evaluation of the suggested DPSK-DD-Optical IOFDM with different MIMO configurations are investigated for the different distances and water types, to identify the key role played by the MIMO technique. The



a) Relationship between OSS scheme and Listen interval



b) Show the relation between the OSS scheme and optimal BI

Fig. 13.

investigation is then expanded to include the DPSK-CD-Optical OFDM technique incorporating other MIMO configurations for different distances and water types. The end-to-end BER of the suggested DPSK-DD-Optical IOFDM, DPSK-CD-Optical OFDM based on various MIMO configurations is calculated for different distances and water types. The analysis of the results attempts to compare the BERs of the proposed DPSK-DD-Optical OFDM with MIMO and DPSK-CD-Optical OFDM with the MIMO system. Also, the diagrams of acceptable received power versus link range for DPSK–CD-Optical OFDM and DPSK-DD-Optical OFDM under clear water, coastal water, and turbid water respectively indicates that higher quantities of bitrates that lead to enhancement in BER.

8 Conclusion

1. It can be concluded from the literature of the architectures proposed for this research of the UOWC system namely DPSK-DD-Optical OFDM and DPSK-CD-Optical IOFDM, the use of coherent detection Optical IOFDM has generated much interest in the study of the next generation of underwater communication systems. This coherent detection optical OFDM has the ability to transmit high data and to overcome underwater impairments, absorption, scattering, and multipath.
2. DPSK-CD-Optical IOFDM records the best performance in receiver sensitivity compared to DPSK-DD-Optical OFDM. This is because like DPSK-CD-Optical OFDM the receiver of DPSK-DD-Optical OFDM is not sensitive to phase, frequency, and polarization.
3. The values of optimal BI and LI did not affect the values of the mean and variance of data packet delay for each station.
4. As MIMO system is able to send and receive multiple signals, it can distinguish the signals sent from different transceivers. Since the MIMOI system enables more data to be transmitted, issues associated with channel impairments such as physical obstructions and turbulence can be solved, therefore minimizing the occurrence of errors. From the simulation results, the highest allowable range for a good link could be further enhanced. The DPSK-CD-Optical OFDM with 4×4MIMO technique has provided relevant solutions to overcome underwater impairments such as absorption and scattering.
5. The simulation result of reliable link range at target BER (10-5) for DPSK-DD-Optical OFDM with 4×4MIMO are recorded as 10.5m, 31m, and 131m for turbid, mid and clear water respectively.
6. The simulation results of reliable link range at target BER (10-5) for the proposed DPSK-CD-Optical OFDM with 4×4MIMO are recorded as 12m, 38.5m, and 156m for turbid, mid and clear water respectively.
7. Finally, the research study concludes with the simulation results of UOWC system using the proposed DPSK-CD-Optical OFDM and MIMO technique. overall, the proposed technique has brought great improvement to the performance of all UOWC especially in terms of data rate and link range.

9 References

[1] T. S. Mansour, F. M. Abdulhussein "Dual Measurements of Pressure and Temperature with Fiber Bragg Grating Sensor. Al-Khwarizmi Engineering Journal, vol. 11, no. 2, pp. 86-91, 2015.

[2] K. R. Patel, and S. K. Mulye, "Free Space Optics (FSO)-Past, Present, Future and Mathematical models of atmospheric turbulence for FSO link budget analysis", IJRITCC, 2016.

[3] P. kumara, and R. Thakur, "review paper: hybrid amplifier in FSO system", international journal of computer technique, vol. 3, no. 2, 2016.

[4] Wen-Shing Tsai, Hai-Han Lu, Chung-Yi Li, Ting-Chieh Lu, Hung-Hsien Lin, Bo-Rui Chen, and Chang-Jen Wu, "A 50 m/320Gbps DWDM FSO Communication with A focal scheme", IEEE Photonics, vol. 8, pp. 1943-0655, 2016. https://doi.org/10.1109/jphot.2016.2555618

[5] H.A. Naman, N. A. Hussein, M. Al-dabag, H. Th.Salim, "Encryption System for Hiding Information Based on Internet of Things," International Journal of Interactive Mobile Technologies (iJIM), vol. 15, no. 2, 2021. https://doi.org/10.3991/ijim.v15i02.19869

[6] P. Sharma, H. Sarangol, J. Malhota, "Determined Effect of Weather Conditions on FSO Based System Survey," International Journal of Application or Innovation in Engineering and Management. vol. 4, no. 6, pp. 74-79, 2015.

[7] I. A.Ibrahim,T. S. Mansour," Walsh Hadamard Code and Wavelength Division Multiplexing Designed and Implemented Using Array FBGs", IOP Conf. Series: Materials Science and Engineering, 1094 ,202. https://doi.org/10.1088/1757-899x/1094/1/012114

[8] N. A. Hussien, H. Alrikabi, F. Abed, "Monitoring the Consumption of Electrical Energy Based on the Internet of Things Applications," International Journal of Interactive Mobile Technologies (iJIM), vol. 15, no. 7, 2021. https://doi.org/10.3991/ijim.v15i07.20183

[9] X. Zhang, J. H. Cui, S. Das, M. Gerla, and M. Chitre, “Underwater Wireless Communications and Networks: Theory and Application: Part 2 [Guest Editorial],” IEEE Commun. Mag., vol. 54, no. 2, pp. 30–31, 2016. https://doi.org/10.1109/mcom.2016.7402257

[10] A. Dawood, T..Mansour, L..T.Mohammed “Electronically Implementation and Detection of Pulse Laser from Continuous Laser Diode” Iraqi Journal of Laser, vol.18, no.2, pp.27-33, 2019.

[11] M. Al-dabag, H. Salim and R. Al-Nima, "Anticipating Atrial Fibrillation Signal Using Efficient Algorithm," International Journal of Online and Biomedical Engineering (iJOE), vol. 17, no. 2, pp. 106-120, 2021. https://doi.org/10.3991/ijoe.v17i02.19183

[12] B. H. Majeed, L.F. Jawad, H. Th. Alrikabi, "Tactical Thinking and its Relationship with Solving Mathematical Problems Among Mathematics Department Students," International Journal of Emerging Technologies in Learning (iJET), vol. 16, no. 9, 2021. https://doi.org/10.3991/ijet.v16i09.22203

[13] B. Majlesein, A. Gholami, and Z. Ghassemlooy, “A Complete Model for Underwater Optical Wireless Communications System,” 2018 11th Int. Symp. Commun. Syst. Networks Digit. Signal Process. CSNDSP 2018, no. July, 2018. https://doi.org/10.1109/csndsp.2018.8471869

[14] I.A. Ibrahim, H.T. Salim, and H.F. Khazaal, "Investigating the Analysis of Power Saving Mode in IEEE 802.11 for Wi-Fi Communication," Wasit Journal of Engineering Sciences, vol. 6, no. 3, pp. 13-19, 2018. https://doi.org/10.31185/ejuow.vol6.iss3.100

[15] P. kumara, and R. Thakur, "review paper: hybrid amplifier in FSO system", international journal of computer technique, Volume 3, Issue 2, 2016.

[16] S. Chaudhary, and A. Amphawn, "4×2.5Gbps=10Gbps RO-FSO Transmission system by Incorporating Hybrid WDM-MDM of spiral phased LG-HG Modes", International Conference on internet applications, protocols and services, pp. 978-967, 2015.

[17] B. Bharathan, B.Reddy Tamma, B. S. Manoj, "A Novel Power Saving Strategy for Greening IEEE 802.11 based Wireless Networks", In Global Telecommunications Conference (GLOBECOM 2010), 2010 IEEE, pp. 1-5. IEEE, 2010. https://doi.org/10.1109/glocom.2010.5684071

[18] Yousif I. Hammadi, Tahreer S. Mansour, A. H. H. Al-Masoodi, and S. W. Harun, “Passively Femtosecond Mod- Locked Erbium-Doped Fiber Oscillator with External Pulse Compressors for Frequency Comb Generation,” Journal of Optical Communication. https://doi.org/10.1515/joc-2019-0240

[19] H. M. Oubei, J. R. Duran, B. Janjua, H.-Y. Wang, C.-T. Tsai, Y.-C. Chi, T. K. Ng, H.-C. Kuo, J.-H. He, and M.-S. J. O. e. Alouini, “4.8 Gbit/s 16-QAM-OFDM transmission based on compact 450-nm laser for underwater wireless optical communication,” Opt. Express, vol. 23, no. 18, p. 23302, 2015. https://doi.org/10.1364/oe.23.023302

[20] J. Xu, A. Lin, X. Yu, Y. Song, M. Kong, F. Qu, J. Han, W. Jia, and N. T. Deng, “Underwater Laser Communication Using an OFDM-Modulated 520-nm Laser Diode,” IEEE

Photonics Technol. Lett., vol. 28, no. 20, pp. 2133–2136, 2016. https://doi.org/10.1109/lpt.2016.2582542
[21] C.-M. Ho et al., “A 10m/10Gbps underwater wireless laser transmission system,” in Optical Fiber Communication Conference, 2017, pp. Th3C-3. https://doi.org/10.1364/ofc.2017.th3c.3
[22] [22] Y. Song et al., “Experimental demonstration of MIMO-OFDM underwater wireless optical communication,” Opt. Commun., vol. 403, no. April, pp. 205–210, 2017.
[23] S. Papadakis, J. Vaiopoulou, M. Kalogiannakis, and D. J. S. Stamovlasis, "Developing and exploring an evaluation tool for educational apps (ETEA) targeting kindergarten children," Sustainability, vol. 12, no. 10, p. 4201, 2020. https://doi.org/10.3390/su12104201
[24] D. Abdul-Rahman Al-Malah, H. Th. Salim, "Enhancement of educational services by using the internet of things applications for talent and intelligent schools," Periodicals of Engineering and Natural Sciences (PEN), vol. 8, no. 4, pp. 2358-2366, 2020.
[25] S. Papadakis, N. Zaranis, and M. Kalogiannakis, "Parental involvement and attitudes towards young Greek children’s mobile usage," International Journal of Child-Computer Interaction, vol. 22, p. 100144, 2019. https://doi.org/10.1016/j.ijcci.2019.100144
[26] P. Dorouka, S. Papadakis, M. J. I. J. o. M. L. Kalogiannakis, and Organisation, "Tablets and apps for promoting robotics, mathematics, STEM education and literacy in early childhood education," vol. 14, no. 2, pp. 255-274, 2020. https://doi.org/10.1504/ijmlo.2020.10026334
[27] M. Drolia, E. Sifaki, S. Papadakis, and M. J. C. Kalogiannakis, "An Overview of Mobile Learning for Refugee Students: Juxtaposing Refugee Needs with Mobile Applications’ Characteristics," Challenges, vol. 11, no. 2, p. 31, 2020. https://doi.org/10.3390/challe11020031
[28] S. Papadakis, "Tools for evaluating educational apps for young children: a systematic review of the literature," 2020.

10 Authors

Isam Aameer Ibrahim obtained his Bachelor degree in Electrical Engineering from College of Engineering, University of Mustansiriya. As well as obtained his Master Degree in Communication Engineering from College of Engineering, University of Uniten. Currently he is studying his PhD’s Degree in Communication and Electronics Engineering at Institute of Laser for postgraduate studies, University of Baghdad. His research interest area focuses on applications of Laser in Communication and Electronics Engineering. Email: isam.omair1101a@ilps.uobaghdad.edu.iq.

Tahreer Safa’a Mansour Ph.D. is a senior lecturer at Institute of Laser for postgraduate studies, University of Baghdad. She obtained her Ph.D. in Communication and Electronics Engineering from Institute of Laser for postgraduate studies, University of Baghdad. She is actively supervising Ph.D. and Masters students in the area of

Communication and Electronics Engineering. She teach Fiber Optics and Fourier Optics subject for postgraduate students. Her intense research areas are in applications of Laser in Communication and Electronics Engineering. Email: tahreer@ilps.uobaghdad.edu.iq.

Article submitted 2021-01-22. Resubmitted 2021-05-04. Final acceptance 2021-05-06. Final version published as submitted by the authors.