



IJEAST

INTERNATIONAL JOURNAL
OF ENGINEERING APPLIED SCIENCE
AND TECHNOLOGY



VOLUME : 6 ISSUE : 4 Print / Issue Publication Date: 17-Oct-2021



ISSN : 2455-2143



Indexed In



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PERFORMANCE ANALYSIS OF UWOC-4QAM-OFDM SYSTEM WITH MIMO

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Abstract— The Underwater wireless optical communication (UWOC) may be a communication system that transmits data in an underwater environment using light. UWOC provides variety of advantages over the underwater radio frequency and acoustic techniques, including a broad unlicensed spectrum with high information bandwidth and low power requirements. A major purpose of this study is intended to grasp the simplest system architecture, practicality, and constancy of high-speed underwater optical communications thanks to various phenomena of propagation that affect the system's performance, like characterization of the channel, modulation techniques, and various noise sources caused by reflection, diffusing, and absorption. The Orthogonal Frequency Division Multiplexing (OFDM) accompanying Quadrature Amplitude Modulation (QAM) by employing Multi-Input-Multi-Output (MIMO) aims to boost data rate and range, which will benefit in the subsequent development of underwater optical communication. The system's performance was assessed in a high turbulent underwater channel and analyzed by changing the link range and the results are presented as comparisons between various data rates.

Keywords— UWOC, OFDM, QAM, high turbid water, FSO, MIMO and Optisystem software.

I. INTRODUCTION

The transmission of signals using visible, infrared, or ultraviolet light is known as wireless optical communication (WOC). WOC has been researched in several links, from ultrashort, short, medium, long, to ultralong range. The underwater communication channel is a tough and constantly changing environment. Absorption, scattering, and turbulence

all have a significant impact on the optical characteristics of saltwater. As a result, angular spreading, deviation off the optical pathway, amplitude and phase aberrations occur in an optical beam travelling in water [7]. The principal cause of light loss in water is attenuation, which is the result of both absorption and scattering. Scattering can result in temporal beam spreading that results in inter-symbol interference (ISI) and affects the BER [8]. In paper [1] the optical communication system with high turbid water as medium has achieved a 10 m range at the data rate of 40 Gbps. In paper [2] the results reveal that varying the depth has a considerable impact on Bit Error Rate (BER) performance, with the BER increasing from 5.25×10^{-6} at 1 m to 1.21×10^{-2} at 30 m. In paper [8] study has demonstrated a variety of systemic level underwater cables with data speeds that are unrivalled. UWOC links of 20 m for 1.5 Gbit/s and 5.4 m for 4.8 Gbit/s were obtained by utilising the simple OOK as well as the spectrally efficient QAM-OFDM modulation methods, respectively. The performance parameters such as Q Factor and minimum BER demonstrate the system's stable variation in the presence of multiple parameters such as attenuation, link range, and laser wavelength

II. SYSTEM ANALYSIS

A. UWOC System using OFDM technique –

An OFDM may be a Technique for multicarrier modulation that utilizes overlap signals to segment the frequency selective channel variety of channels with a narrow band and a flat fading effect. Rather than delivering the information sequentially on one carrier at a high symbol rate, the FFT encrypts the block of symbols. By spacing the subcarrier as symbol time increases, the subchannels become orthogonal. When compared to multipath delay spread, multipath fading is generally eliminated by lengthening the



symbol period of the sub-channel. Signals with a lot of noise and interference are disabled, which reduces the fading and interference impact. Within the transmitter and reception sectors of the radio, complicated signal processing technologies like the Fast Fourier Transforms (FFTs) and inverse FFTs are used to develop the OFDM modulation technology. One of the advantages of OFDM is its ability to combat the negative effects of multipath propagation in terms of inter-symbol interference during a channel. Because the channels are overlapping and contiguous, OFDM is also spectrally efficient. [1].

In QAM (quadrature amplitude modulation), two AM (amplitude-modulated) signals are combined into a single channel to double the effective bandwidth. There are two carriers in a QAM signal, each of which has a different phase by 90 degrees (hence the term quadrature). The I signal is one type of signal, while the Q signal is the opposing type. The opposing signal is commonly represented mathematically as a sine wave, and the former as a wave. When the two modulated carriers are being transmitted, they will be merged together at the source. The carriers are separated at the destination, and data is taken from each carrier, and then the data is concatenated to produce the principal modulating information. Fig. 1 depicts the UWOC-4QAM-OFDM system's conceptual architecture, data creation, and underwater transmission. After dividing a binary bit sequence into low-speed data blocks, QAM symbols are then mapped on top of the blocks. Data from reference are frequently used to provide information about serial-to-parallel mapping of data and encoding processes [1] [4]. With the use of an FFT, the inverse fast Fourier transform (IFFT) unit transforms QAM symbols into the corresponding OFDM signals.

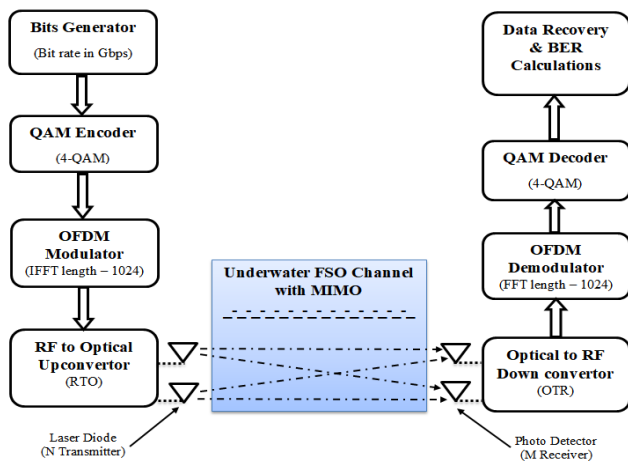


Fig 1. Block diagram of UWOC-4QAM-OFDM system

The signals are pre-amplified after DAC and superimposed on the DC bias current by using the RF connection of the built-in Bias-tee mounted within the diode mount, which

directly encoding the 532nm Laser diode signal. A cyclic prefix (CP) is introduced to the transmission connection to reduce inter-symbol interference (ISI). In order to achieve the critical peak-to-average power ratio (PAPR) in a modulated 4QAM-OFDM data stream, the DC bias point of the 532 nm Laser diode must be adjusted. The optical 4QAM-OFDM data stream is created by converting the RF-to-optical domain in accordance with the 532 nm LD's power-to-current response.

B. Multiple Input Multiple Output –

The use of spatial diversity is one method of enabling a large number of laser sources at the transmitter or photo detector at the receiver. With each joint getting a light detector in addition to the UWOC receiver, it is possible to directly enhance the channel's throughput. Fig. 2. Illustrates the essential Multiple input multiple output configuration of transmitter and receiver.

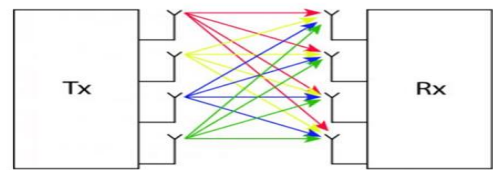


Fig. 2. Transmitter and receiver setup using MIMO

Because of the media channel disruption in the Free Space Optics Channel, there is a possibility of a decrease in attenuation inside the received signal. It is feasible to reduce the weakening by employing some diversification approaches. Lasers at the transmitter and photo detector at the receiver provide a variety of beam paths with this technique. Transmitters transmit optical signals, which are delivered through lenses in a variety of ways. In general, the MIMO approach can be represented using MT transmitters (laser diodes) and MR receivers (photodetectors) by (2).

$$p(t) = q(t)*r(t)+s(t) \quad (1)$$

Where $p(t)$ is the $MR \times 1$ receiver vector, $r(t)$ is the $MT \times 1$ transmitter vector, $p(t)$ is the $MR \times MT$ channel transfer matrix with entries ith representing the antenna transfer function for the jth transmitter antenna and ith receiver antenna, and $s(t)$ is the $MR \times 1$ additive noise vector, and $v(t)$ is the $MR \times 1$ additive noise vector. MIMO's potential rests in the techniques of pre and post processing the broadcast and received vectors ($r(t)$ and $p(t)$, respectively), which can exploit the fact that the elements of $p(t)$ are not identical, which implies interference between particular antenna pairs. In the context of MIMO systems, diversity refers to a system's ability to improve performance by varying the transfer operation across antenna pairs.



The basic notion of diversity gain might be a way for determining how diverse a design is. In any UWOC, the gain of diversity quantifies the decrease in the likelihood of mistake in relation to signal-to-noise ratio (SNR). It is used to calculate the value (2).

$$\left(\frac{P_e(y)}{\log y}\right) = -d^1 \quad (2)$$

$P_e(y)$ represents the average probability of error at $SNR=y$, and d^1 represents the gain of diversity [1].

C. Optisystem Software –

The Optisystem is a cutting-edge, rapidly developing, and highly successful software programme design tool that allows users to model, test, and simulate nearly any type of optical connection in the transmission layer of a wide range of optical networks, from LAN, SAN, and MAN to ultra-long-haul. In addition to visual assessments and scenarios, it enables the planning of optical communication devices from a technical perspective to their device level.

III. SIMULATION AND RESULTS

A. Design Specifications for the UWOC-4QAM-OFDM system –

The design parameters are considered in this work by taking the input bitrate, which is chosen to vary from 10 Gbps to 120 Gbps and is encoded by the QAM encoder.

To create high-speed OFDM analogue data signals, the proposed system uses encoded 4-QAM signals that are subsequently OFDM modulated by an OFDM modulator with 512 sub-carriers and an FFT size of 1024.

Typically OFDM analogue signals are modulated using a carrier of light produced by a continuous-wave laser signal with a wavelength of 532 nm and a power of 30dBm in transmitter and receiver antenna configurations that employ this data rate. The modulated optical signal is amplified prior to transmission into the free space channel. The gain of the amplifier is around 20dB.

The FSO channel is then used to send the amplified signal straight to the receiver. The transmitter and receiver are adjusted to have apertures of 5 cm and 20 cm, respectively.

The proposed system has been designed in order to achieve better link range, hence MIMO (8x8) configuration has been taken as channel improvisation strategy by configuring the FSO channel with eight transmitters and eight receivers. The MIMO strategy enables spatial diversity through which the system can achieve better performance.

Table -1 Design specifications of the system

Parameter	Value	Description
Bit Rate	10, 20, 40, 80 and 120 Gbps	Symbol rate = Bit rate*1/2 (UWOC-4QAM-OFDM)
Modulation	4-QAM	2 bits/symbol
OFDM Sub carriers	512	IFFT/FFT Points = 1024, Prefix points = 64
CW Laser Diode Wavelength & Transmission Power	532 nm & 1 Watt	Low absorption & Scattering
Optical Amplifier	20 dB & 4 dB	Gain & Noise Figure
Local Oscillator Wavelength & Power	532 nm & 1 Watt	-
PIN Photodetectors - 4 Nos.	Responsivity = 1 A/W	Dark Current = 10 nA $R_L = 50 \text{ Ohm}$
Thermal Noise & Shot Noise	$1 \times 10^{-22} \text{ W/Hz}$	Absolute Temperature = 298 K
Low Pass Filters - 3 Nos.	$0.62 \times \text{symbol rate}$ $0.75 \times \text{symbol rate}$	Cut-off frequencies of Cosine Roll-off & Chebyshev filters

Table – 1. displays the proposed parameters for the proposed system that will be used to get the best performance out of the system. The simulation parameters are chosen based on the system's design requirements.

B. Channel Specifications for the UWOC-4QAM-OFDM system –

Light propagation in water is hampered by two phenomena: absorption and scattering. Light propagating through water in low scattering regimes is explained using the wavelength function $c(\lambda)$. $c(\lambda)$ is a coefficient constructed using the total effects of both the absorption and scattering coefficients, represented by $a(\lambda)$ and $b(\lambda)$, respectively (3).

$$c(\lambda) = a(\lambda) + b(\lambda) \quad (3)$$

For simplicity without compromising generality, different values of concentration chlorophyll C are typically employed to define different types of waters. The coefficient of absorption $a(\lambda)$ and coefficient of scattering $b(\lambda)$ may be expressed as a function of wavelength and concentration C using (4) and (5).

$$a(\lambda) = [aw(\lambda) + 0.06ac(\lambda) C^{0.65}] \{1 + 0.2 \exp[-0.014(\lambda - 440)]\} \quad (4)$$

$$b(\lambda) = 0.30 (550/\lambda) C^{0.62} \quad (5)$$

Where a_w is the clean water absorption coefficient and a_c is a nondimensional value derived from statistics that reflects the chlorophyll absorption coefficient.

As a consequence, the chlorophyll concentration C , given in mg/m^3 , may be used as a free parameter for computing $a(\lambda)$ and $b(\lambda)$.

Table - 2. Attenuation values for high turbid water types [4].

Water Types	Chlorophyll concentration C (mg/m^3)	Absorption coefficient $a(\lambda)$ (m^{-1})	Scattering coefficient $b(\lambda)$ (m^{-1})	Total Beam Attenuation $c(\lambda)$ (m^{-1})
Turbid Harbour I	2.99	0.149	0.950	1.100
Turbid Harbor water II	5.9	0.295	1.875	2.170

Table - 2 shows the values measured for absorption $a(\lambda)$, total scattering $b(\lambda)$, and ratio of extinction of $c(\lambda)$. It's worth noting that the absorption measurements for the input optical signal were taken in a spectral band with a centre wavelength of 532 nm.

Table - 3. contains the FSO channel parameters of the proposed system in which water is used as the transmission medium and attenuation of high turbid harbour II water type is taken into account. As a result, the system was tested with a beam divergence of 2 mrad at various data rates and additionally with the MIMO (8x8) configuration.

Table - 3. Specifications is FSO channel

Parameter	Value	Description
Channel Medium	Water	Turbid Harbor II
Channel Attenuation	2170 dB/km	Total Optical Beam Attenuation
Range	35 m - 41 m	Short Distance Link
TX/RX aperture diameter (multi carrier)	5 cm/20 cm	Beam Divergence = 2 mrad
Tx/Rx Configuration	8x8	MIMO

In this work, the schematic diagram as shown in Fig. 3. was designed and developed for the UWOC system using the 4QAM modulation scheme using the various components available in Optisystem such as BER test set, QAM coders, OFDM modulators, filters, laser diodes, FSO channel, PIN diodes, BER analyzer, and so on. Other components, such as, Optical amplifiers, couplers, modulators, power combiners, etc. were used to design subsystems.

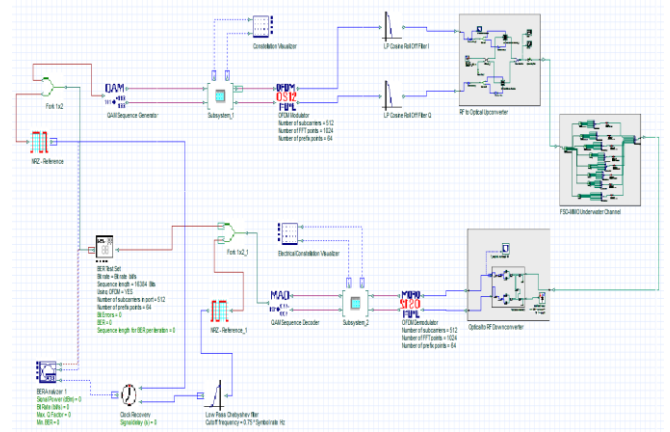


Fig. 3. UWOC-4QAM-OFDM System schematic diagram

In Fig. 4. Each MZM modulator one among the baseband OFDM (I or Q) signal components at the 2 inputs of the M&M's modulation signal is supported by positive and negative signals.

Both MZMs' output signals are combined into a complex optical OFDM signal that is amplified and sent via the optical combiner. The in-phase (I) and quadrature (Q) of the next signals from the OFDM modulator is then fed to the RTO subsystem.

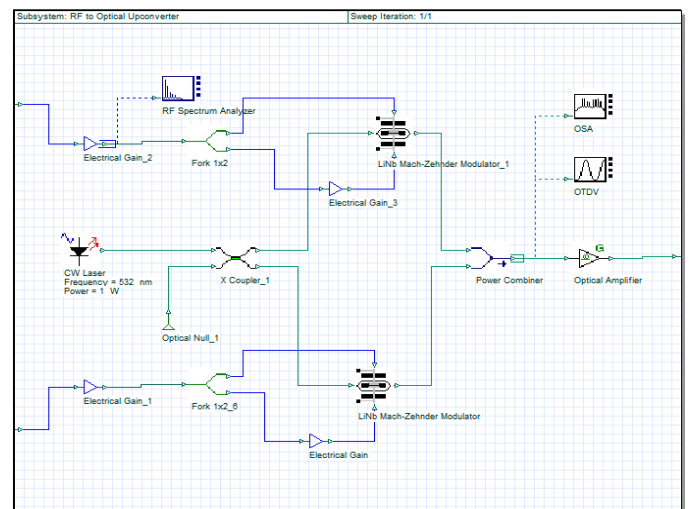


Fig. 4. RF to Optical (RTO) Conversion subsystem

In the UWOC-4QAM-OFDM system, the FSO channel is used in conjunction with the diversity scheme, as illustrated in Fig. 5. Multiple Tx/Rx architecture is used in this case, with an 8x8 arrangement.

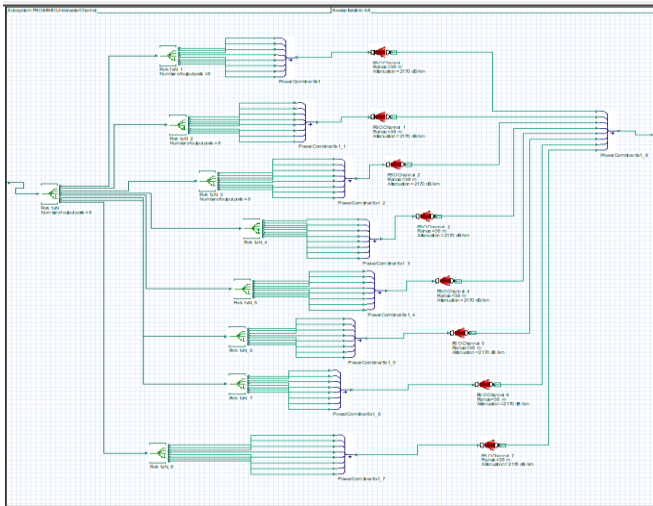


Fig. 5. (MIMO) implementation in UWOC-4QAM-OFDM system's FSO channel using 8 Tx/Rx.

Spatial diversity is a strategy that involves using different transmitters or receivers at different places so that the signal remains stable and does not suffer from deep fading.

The OTR subsystem as illustrated in Fig. 6. is using stable noise detectors. To separately extract the (I) and (Q) modules in the OFDM, the first coupler splits the incoming Optical OFDM complex signal into two parts.

Likewise, the second coupler is utilized to break apart the local oscillator (LO) signal into two portions to be blended with the Optical OFDM signal in the (I) and (Q) divisions.

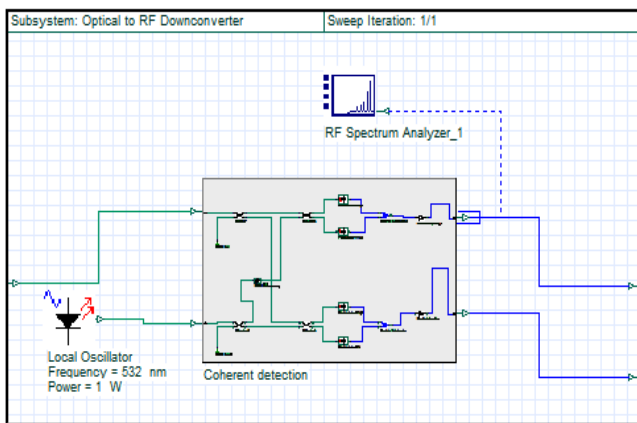


Fig. 6. OTR subsystem with Coherent detection

From Fig. 7 Clearly, the UWOC-4QAM-OFDM system has attained a better link range with lower data rates.

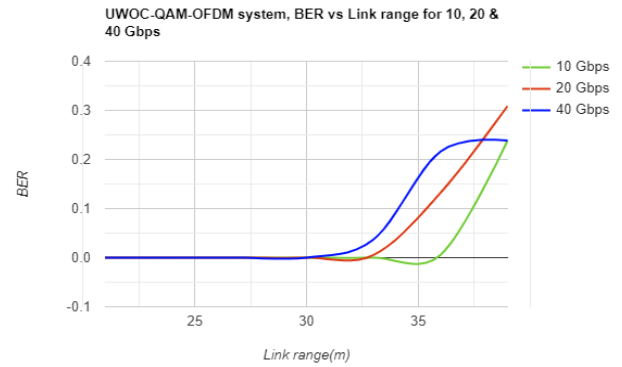


Fig. 7. UWOC-4QAM-OFDM system BER performance variation with range at lower data rate input.

Table - 4. shows that UWOC-4QAM-OFDM has obtained the link range of 33 m at 10 Gbps, 30 m at 20 Gbps and 29 m at 40 Gbps.

Table – 4. UWOC-4QAM-OFDM system BER performance with link range variation for different data rates

Range (m)	BER at 10 Gbps	BER at 20 Gbps	BER at 40 Gbps
21	0	0	0
24	0	0	0
27	0	0	0
30	0	0	0.00013
33	0	0.00533	0.03710
36	0.00585	0.13229	0.21621
39	0.23841	0.30898	0.23841

It is observed that the link range can be improved if the system transmits the data in lower data rates.

From Fig. 8. It is clear that the UWOC-4QAM-OFDM system with MIMO technique achieved a good link range with higher data rates and there is significant improvement compared to the system without MIMO technique.

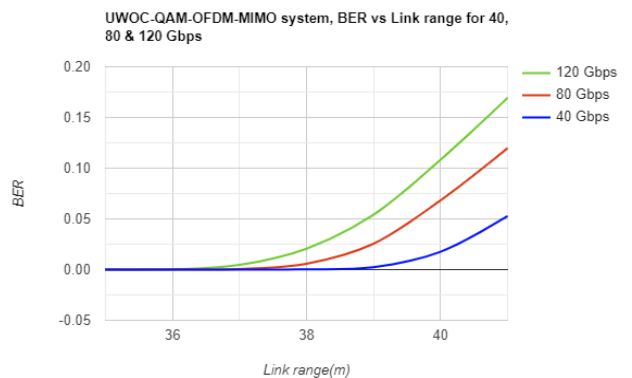


Fig. 8. UWOC-4QAM-OFDM system BER performance variation with range at different data rates.



Table - 5. shows that UWOC-4QAM-OFDM has achieved the link range of 37 m at 40 Gbps, 36 m at 80 Gbps and 35 m at 120 Gbps.

Table - 5. UWOC-4QAM-OFDM system BER performance with range variation for different data rates at 2 mrad

Range (m)	BER at 40 Gbps	BER at 80 Gbps	BER at 120 Gbps
35	0	0	0
36	0	0	0.00039
37	0	0.00058	0.00468
38	0.00032	0.00585	0.02068
39	0.00247	0.02552	0.05410
40	0.01764	0.06835	0.10839
41	0.05286	0.11985	0.16946

It is clear that there is a noticeable variation in system performance with incorporation of MIMO technique, the link range reduces as the data rate rises.

IV. CONCLUSION

In this work it's observed that the UWOC-4QAM-OFDM system with proposed parameters for high turbid harbor II water type as medium has achieved a link range of 29 m at 40 Gbps, however, there's a clear improvement of 27.58% increase in link range by the addition of MIMO to the system. Therefore, the UWOC-4QAM-OFDM system with MIMO (8X8) configuration transmitted the optical signal to a link range of 36 m at 120 Gbps. As a result, the system should be designed according to the trade-offs between link range and data rate at the permissible BER.

V. ACKNOWLEDGMENT

We are extremely thankful to Prof **Dr. K Sreelakshmi**, Head of the Department (Electronics and Telecommunication), and Principal **Dr. K N Subramanya** for providing us with the infrastructure needed to complete this study work paper. Sincere gratitude is extended to all of the professors at RV College Engineering in Bangalore, India. Finally, to all the family members and friends who supported us in the course of our entire work.

VI. REFERENCE

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