Performance Analysis of Underwater Wireless Optical Communication System

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***Abstract*— In recent times Underwater optical wireless communication (UOWC) systems have been receiving a great deal of attention because of their advantages of higher data rates, lower latency, and security while comparing it to the traditional acoustic communications. However, the problem is that the transmitting length is relatively short compared to the traditional acoustic communication and RF communications. It is because the light beam in the channel suffers from absorption, scattering, and the turbulence fading of the water channel. Despite these drawbacks, UOWC is still one of the promising technologies. Thus, exploring UOWC to its full potential has become an utmost important for us to have an effective communication. In this paper, we have been experimenting with different mapping schemes like QAM-OFDM and PSK-OFDM with different orders, along with different error correction encoding techniques to analyse the performance of the signal based on its transmitting length and their Bit error rate (BER). At the end of this paper, we can find out which combinations of modulation techniques, along with encoding, provide greater transmitting lengths and lower bit error rates (BER).**

I. Introduction

Around 75% of the earth is covered with water. It contains a large number of natural resources, and to explore these resources, the development of an effective underwater wireless communication system became very important, due to several applications like scientific marine exploration, voice and data communications between drivers, mine reconnaissance, the study of disasters, military projects, many more. The applications of underwater wireless optical communication (UWOC) is rapidly increasing. For example, ocean monitoring, ocean exploration, undersea expeditions, So, obviously, it is one of the vital communication media for communication researchers [1-3].

The underwater environment is a very harsh and dynamically changing communication channel. The optical properties seawater is strongly affected by absorption, scattering, and turbulence. As a consequence, the optical beam propagating in water experiences angular spreading, deflection from the optical path, and amplitude and phase distortions. Besides, the transmitter beam is collimated with a minimal diameter leading to unavoidable link misalignments. These phenomena ultimately translate to low SNR and poor BER performance. Attenuation, which is a combined effect of absorption, and scattering is the leading cause of light loss in water. Absorption($a(\lambda)$) is the process in which the photon energy is lost due to the transfer of power during the interaction with water molecules, dissolved organic matters, and particles. In scattering($b(\lambda)$), the photons are scattered away from the original path after interacting with particulate matter in the water. Scattering may cause temporal beam spreading, which results in inter-symbol interference (ISI) and degrades system BER performance. As a consequence, underwater wireless optical links are limited to much shorter ranges [4-12].

The combined effect of these two processes represents the total beam attenuation coefficient

$$c(\lambda) = a(\lambda) + b(\lambda) \tag{1}$$

However, current acoustic communication technologies can only provide limited data rates due to the narrow bandwidth available as well as extended multipath spreading in the underwater channel. The Radiofrequency (RF) communication, is one alternate option for underwater wireless communication when used for high data rate transfer in short distances. The speed of EM waves mainly depends upon permeability(μ), permittivity(ϵ), conductivity(σ) and volume charge density(ρ) which varies according to the type of underwater conditions and frequency be infused. It has been observed that the attenuation of RF waves increases with the increase in rate and is heavily attenuated by seawater [13]. Due to these drawbacks of existing methods to communicate in an Underwater channel, UWOC has been receiving considerable attention because of its potential to transmit signals with high data rates and lower latency compared to the traditional methods.

Although the transmitting length is relatively short in an Underwater wireless optical communication, UOWC is still a promising technology in many applications. Even today, UWOC is not used to its full potential.

Most of the channel models on underwater wireless channel (UWOC) are based on adding noise to the channel such as white gaussian noise. The results simulated are based on observing BER while increasing noise in the channel. The results generated from this channel does not account for varying lengths of channel, absorption or scattering coefficients. Thus, this method cannot be ideal for performance analysis of the of the channel. To test the Real performance of an UWOC one must account for these varying real-time parameters.

The primary objective of this paper is to simulate an impulse response function for an Underwater wireless channel for different Field of views (FOV) with primary factors affecting the channel's performance being scattering coefficient, absorption coefficient and length of the channel. From the simulated impulse function of an Underwater channel, we transmit signals using different mapping schemes, namely OFDM with 4-QAM, 16-QAM, and OFDM with 4-PSK, 16-PSK, and use error correction codes such as LDPC and BCH encoding methods. From the received signal we analyze the performance of each signal in an underwater channel based on their Bit error rate and the maximum distance the signal can travel in a channel.

II.PROPOSED DESIGN FOR PERFORMANCE ANALYSIS

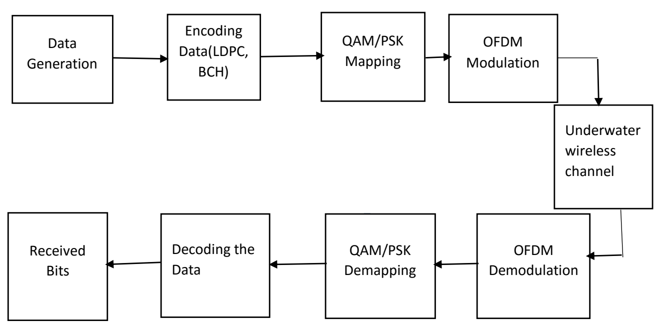

Fig 1 Block diagram for the proposed model

This project's design can be divided into three parts, i.e., Transmitter, receiver, and channel. We will see the function of each part in the subsequent sections.

A. Transmitter:

Initially, we start with the generation of data; the data points we used for this experiment is 32400 bits. For the data point, we randomly assign 0's and 1's up to 32400 bits. After the data generation, we then encode the data using error correction methods like LDPC and BCH techniques. After the encoding, the data points are doubled and tripled for LDPC and BCH encoding, respectively. Next, we move to modulation or mapping of the encoded data to 4 QAM, 16 QAM, 4 PSK, 16 PSK. After the mapping of data points. We feed it into Orthogonal frequency division multiplexing (OFDM).

B. Channel:

We simulate the water channel using the impulse function called COMBINATION OF EXPONENTIAL AND ARBITRARY POWER FUNCTION (CEAPF)[14]

$$h(t) = C_1' \frac{(b\Delta L)^{\alpha}}{(b\Delta L + C2')^{\beta}} \cdot e^{-a/b.b\Delta L}.e^{-a/b.bL} \quad (2)$$

where $\Delta L = v\Delta t$, $C_1' = (bv)^{\beta-\alpha}C_1$, and $C_2' = bvC_2$,.

Where C1, C2, β, and α are the four parameters to be found and (a) is Absorption coefficient, (b) scattering coefficient, and the (l)length of the channel. This CEAPF equation (i.e., Eq. (2) is a function of three real-world parameters like Absorption(a), scattering coefficients(b), and the length(l) of the channel, which majorly affects the channel's performance in real-time. Thus, in this CEAPF equation, we have the flexibility to input the values of these three parameters manually, which is the primary reason for us to choose this CEAPF equation for the performance analysis channel. However, we are only going to vary the length parameter of the channel to simulate a channel function. For rest, the parameters we are going to use already available data [14]. Then we transmit this generated OFDM signal into the simulated water channel. For this purpose, we convolve two functions, (i.e., channel impulse function and the generated OFDM function). The channel impulse function is of two kinds, and the first one is the harbour water channel and the coastal water channel. We can see that the difference between these two water types is that they differ in their Absorption and scattering coefficients, and the equation constants. The coastal water has relatively low absorption and scattering coefficients compared to the harbour water. Once the convolution takes place, we move into the receiver.

C. Receiver:

In the receiver, we first demodulate the received OFDM signal after the convolution with the channel. Then we can apply the QAM/PSK de-mapping to the demodulated signal. After the de-mapping, we will decode the data which initially encoded in the Transmitter using BCH or LDPC error correction codes. After the signal decoding, we move to find the Bit error rate of the received signal. For this purpose, we compare every bit received against every bit transmitted. Then we divide the error bits from total bits to arrive at the BER rate. Until this process is just the end of the first cycle, for the next cycle, we increase the length of the channel and repeat the same process until the BER is maximum, and the received signal is no longer able to reach this length. With this cycle, by increasing the length of the signal after each iteration, we can find the maximum distance a signal can travel in a particular channel.

We simulate all the processes mentioned above for a different combination of error correction encoding techniques (i.e., LDPC or BCH) and different mappings (i.e., 4 QAM, 16 QAM, 4 PSK, 16 PSK) and different water types. At the end of all these simulations, we can conclude that which water channel will allows us to transmit longer distance and which combination of error correction encoding and mapping schemes offers maximum length with a low Bit error rate (BER).

III. Constraints, and Tradeoffs

The primary constraint of this project is that even though the real-time water channel impulse function is affected by absorption, scattering, turbulence-induced fading caused by temperature and salinity of water, as well as randomly distributed air bubbles in the water. However, to reduce the complexity of the analysis, we have only taken the effects of absorption and scattering, the properties of which can be described by the inherent optical properties (IOPs) of the water.

This papers channel impulse function CEAPF function [14] offers channel response for only two different channel type, i.e., harbour water and coastal water. Moreover, we do not have enough data to simulate channel for other water types, other than the types mentioned above. Thus, our paper is limited to only these two water types. Furthermore, the base paper provides equation constraints only for three different Fields of views (FOV)(i.e., FOV=180,40,20). Thus, this project contains results only to these three different FOV's.

In this water channel, we have experimented with 4-QAM, 16-QAM, 4-PSK, 16-PSK. We were limited to modulation order of 16 because, when we increase the modulation order, the data rate increases; thus, the signal attenuates massively even for short link lengths. Moreover, we were not able to receive the message signal above the modulation order of 16.

When we see the BER vs Length output graph of the PSK modulation, we can observe that the plot suddenly stops after reaching its peak, unlike QAM modulation, where the plot continues even after reaching the peak. This behavior is only seen in PSK because, after a certain length, only half of the transmitted signal is received. Since this graph is a computer-generated, we cannot decode the message when only half of the signal is received. So, after a certain length, we stop simulation manually to avoid the error.

IV. Graphs and Results

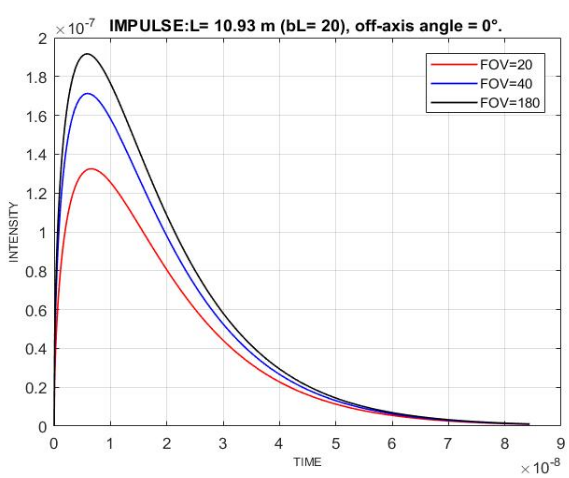

Fig. 2 Impulse response of channel L=10.93m of harbour water

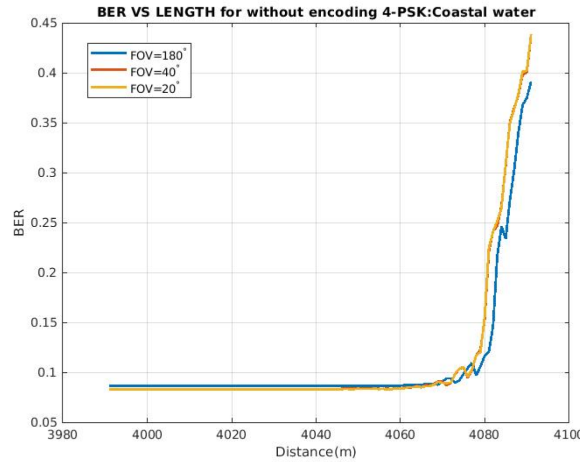

Fig. 3 BER VS LENGTH For 4-PSK signal Without Encoding for Coastal Water

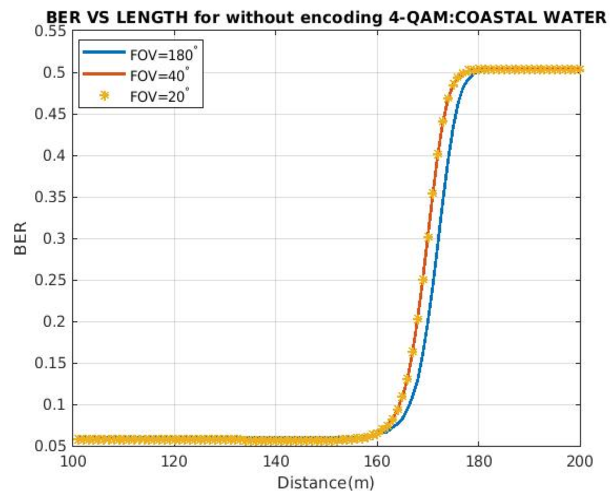

Fig. 4 BER VS LENGTH For 4-QAM signal Without Encoding for Coastal Water

These above Fig 2, Fig 3, and Fig 4 are only a small representation of all the simulations we have undertaken. The results of all the simulations have been recorded and presented in Table.1

Table.1

S.no	Modulation	Modulation order	Encoding	BER(HARBOUR)	BER(COASTAL)	Max.distance(m) HARBOUR	Max.distance(in m) (COASTAL)
1	QAM-OFDM	4	BCH	0.0717	0.0525	62	161.9
2	QAM-OFDM	4	LDPC	0.1739	0.126	62	161.9
3	QAM-OFDM	4	NIL	0.1343	0.0601	62	161.9
4	PSK-OFDM	4	BCH	0.1238	0.0617	1982	4076
5	PSK-OFDM	4	LDPC	0.1739	0.1231	1982	4076
6	PSK-OFDM	4	NIL	0.1725	0.08451	1982	4076
7	QAM-OFDM	16	BCH	0.307	0.2786	62	161.9
8	QAM-OFDM	16	LDPC	0.4919	0.49858	48	161.9
9	QAM-OFDM	16	NIL	0.3378	0.3099	62	161.9
10	PSK-OFDM	16	BCH	0.3615	0.3021	1982	4081
11	PSK-OFDM	16	LDPC	0.2786	0.2264	1982	4081
12	PSK-OFDM	16	NIL	0.3753	0.3235	1982	4081

V. Discussion

This Table.1 contains a total of 24 separate combinations of different modulation orders with encoding techniques in two different water channels (i.e., coastal and harbour channel).

As we know that the primary aim of this paper is to find out the max length a signal can travel in a channel, and also find out the minimum Bit error rate (BER) a channel offers. Another goal is to find whether encoding of the signal provides any lower BER to the channel. As far as our aim is considered, the results we obtained are very promising and also answers our question that encoding the signal can offer lower BER. However, it is also true that not all encoding techniques provide lower BER for the transmitting signal.

Usually, we would assume that, in a BER vs Length graph, that BER rate would gradually increase with respect to the length and reach the maximum BER. However, the results we obtain are contradictory to our assumption. If we look at Fig.3 and Fig.4, we can observe that BER stays constant and does not vary with length. However, after some point in length, the BER exponentially rises and reaches its maximum value. This observation is true for both Coastal and harbour water, and This leads us to the conclusion that every channel will have its maximum capacity. Moreover, until or unless its capacity is reached, the Bit error rate neither decreases nor increases. This behavior can also be seen in [15]

When we look at the results table, we can see that BER is relatively low for BCH encoded signals while comparing it to the non-encoded message signal for their respective counterparts. Even though BER is relatively small, the encoding techniques we used do not provide longer transmitting length than the non-encoded signal. Thus, we can conclude that the encoding the signal offers low BER for it does not provide longer transmitting length.

In Table.1, we can see that there are two separate types of channels are used, coastal and harbour water channel. We can observe that the BER is 22% lower for coastal water channels than the harbour water for the same signal. Furthermore, we can also evidently see that in the coastal channel, the message signal easily travels almost 61.4% and 51% more length than it travels in the harbour water of QAM and PSK signals, respectively.

In the results, we see that the BER is much higher for the modulation order of 16. that is because with increasing the modulation order, the data rate increases. Hence we conclude that that BER increases with increasing data rates.

One of the abnormal behaviour we observe in the table is that the LDPC encoded signal offers higher BER than the non-encode signals and BCH encoded signal. To justify this behaviour, we have found out that the LDPC code can be recommended as more effective if the signal to noise ratio (SNR) is more significant than 7dB[16] as we know that in coastal water channel that SNR is lower than 7dB. Hence the LDPC encoded signal offers higher BER.

When we compare the results of transmitting length provided by QAM modulation and PSK modulation, we can see that PSK modulation offers nearly 96% more transmitting length than QAM modulation in both Coastal and harbour water channels. Thus we can conclude that PSK offers a more significant transmitting length than it is offered by QAM modulation.

VI. CONCLUSION

In this project, we have modelled an underwater channel response for Harbour and coastal water. Then we have analyzed the BER vs Length performance for these different Underwater wireless channel types. We have transmitted several signals with varying combinations of mapping schemes and error correction codes with different modulation orders. After all the simulations, it is quite clear that any signal transmitted in an underwater wireless channel suffers substantial attenuation due to parameters like absorption and scattering. This is a drawback. However, according to our results in Table.1, the maximum transmitting distance, a signal can travel is varying from 48m-4076m. The maximum distance we achieved in Underwater channel with the lowest BER is 4-PSK signal encoded with BCH error correction code is 4076m at FOV=1800 in a coastal water channel.

This transmitting distance is promising, where it can be used for various applications like Unmanned underwater vehicles, submarines, ships, and underwater sensors. We can also deploy this to gather essential data such as real-time videos environmental and security data, which may be time sensitive[17].However according to recent findings the maximum estimated distances of 144 m and 117 m with corresponding BERs of 1.89 × 10-3 and 5.31 × 10-4 at were acquired in UWOC system using on-off keying (OOK) modulation scheme, respectively[18], and also , Sonardyne has commercialized the BlueComm UWOC system which can operate over distances of up to 200 m [19], and 16-QAM OFDM signal travel 10.2 m with BER of 2.4×10-3 in a seawater channel[15], comparing to these data, the results we obtained is very reassuring that Underwater wireless channel has very high potential.

However, in this project, we have deployed only error correction codes like LDPC and BCH to control bit error rate. We have not used equalization techniques like Volterra or least mean square methods to control error. We further propose to incorporate different equalization techniques to enhance the performance of our system. Using these methods, the bit-error rate can be brought down by a significant number, and it also possible to increase the transmitting length.

References

[1] B. Cochenour, L. Mullen, A. Laux, and T. Curran, "Effects of Multiple Scattering on the Implementation of an Underwater Wireless Optical Communications Link," OCEANS 2006, Boston, MA, 2006, pp. 1- 6, DOI: 10.1109/OCEANS.2006.306863.

[2] Yoong, Hou Pin, Kiam Beng Yeo, Kenneth Tze Kin Teo, and Wei Loong Wong. "Underwater wireless communication system: Acoustic channel modeling and carry frequency identification." (2009) International Journal of Simulation, Systems, Science and Technology 13, no. 3C:pp. 1-6.

[3] Kumar, P.V., Praneeth, S.S.K. and Narender, R.B.,. "Analysis of optical wireless communication for underwater wireless communication". (2011) International Journal of Scientific & Engineering Research, 2(6), pp.194-202.

[4] Huihui Zhang, Yuhan Dong. (2016). “General Stochastic Channel Model and Performance Evaluation for Underwater Wireless Optical Links” in IEEE Transactions on Wireless Communications (Volume: 15 , Issue: 2 , Feb. 2016); Page(s): 1162 – 1173; INSPEC Accession Number: 15785893; DOI: 10.1109/TWC.2015.2485990

[5] Xueyi Geng ; Adam Zielinski. (2002). “An eigenpath underwater acoustic communication channel model”. Published in ‘Challenges of Our Changing Global Environment'. Conference Proceedings. OCEANS '95 MTS/IEEE, Publisher: IEEE, DOI: 10.1109/OCEANS.1995.528591; INSPEC Accession Number: 5225669, Conference Location: San Diego, California, USA.

[6] R. Galvin, R.E.W. Coats. (2002). “A stochastic underwater acoustic channel model”. Published in: OCEANS 96 MTS/IEEE Conference Proceedings. The Coastal Ocean - Prospects for the 21st Century, DOI: 10.1109/OCEANS.1996.572599, Publisher: IEEE, Conference Location: Fort Lauderdale, FL, USA.

[7] Albert F. Harris, Michele Zorzi. (2007). “Modeling the underwater acoustic channel in ns2”, Publication: ValueTools '07: Proceedings of the 2nd international conference on Performance evaluation methodologies and tools, October 2007, Article No.: 18, Pages 1–8.

[8] Hassan Makine Oubei, Emna Zedini, Rami T. ElAfandy, Abla Kammoun, Mohamed Abdallah, Tien Khee Ng, Mounir Hamdi, Mohamed-Slim Alouini, and Boon S. Ooi. (2017). “Simple statistical channel model for weak temperature-induced turbulence in underwater wireless optical communication systems”. Vol. 42, Issue 13, pp. 2455-2458. Publisher: Optical Society of America. 62

[9] F. De Rango ; F. Veltri ; P. Fazio. (2012). “A multipath fading channel model for underwater shallow acoustic communications”. Published in: 2012 IEEE International Conference on Communications (ICC). Publisher: IEEE, DOI: 10.1109/ICC.2012.6364590, Conference Location: Ottawa, ON, Canada.

[10] Christian R. Berger, Shengli Zhou, James C. Preisig , Peter Willett. (2009). “Sparse Channel Estimation for Multicarrier Underwater Acoustic Communication: From Subspace Methods to Compressed Sensing”. Published in: IEEE Transactions on Signal Processing (Volume: 58, Issue: 3, March 2010). Publisher: IEEE. Page(s): 1708 – 1721, DOI: 10.1109/TSP.2009.2038424.

[11] Sermsak Jaruwatanadilok. (2008). “Underwater Wireless Optical Communication Channel Modeling and Performance Evaluation using Vector Radiative Transfer Theory”. Published in: IEEE Journal on Selected Areas in Communications (Volume: 26, Issue: 9, December 2008). Publisher: IEEE, Page(s): 1620 – 1627, DOI: 10.1109/JSAC.2008.081202.

[12] Guoqing Zhou ; Taebo Shim. (2008). “Simulation Analysis of High Speed Underwater Acoustic Communication Based on a Statistical Channel Model”. Published in: 2008 Congress on Image and Signal Processing. Publisher: IEEE, DOI: 10.1109/CISP.2008.85, Conference Location: Sanya, Hainan, China

[13] J. Lloret, S. Sendra, M. Ardid, and J. J. P. C. Rodrigues, “Underwater Wireless Sensor Communications in the 2.4 GHz ISM Frequency Band,” Sensors, vol. 12, no. 4, pp. 4237–4264, Mar. 2012.

[14] Yiming Li, Mark S. Leeson, and Xiaofeng Li, "Impulse response modeling for underwater optical wireless channels," (2018) Appl. Optical society of America 57, pp.4815-4823

[15] Wu TC, Chi YC, Wang HY, Tsai CT, Lin GR. Blue laser diode enables underwater communication at 12.4 Gbps. Sci. Rep. 2017;7:40480. doi: 10.1038/srep40480

[16] Uryvsky, L.O. and Osypchuk, S.O., (2014). “Comparative analysis of LDPC and BCH codes errorcorrecting capabilities.”Published in: Information and telecommunication sciences (pp. 5-9)

[17] S. Jaruwatanadilok, "Underwater Wireless Optical Communication Channel Modeling and Performance Evaluation using Vector Radiative Transfer Theory," in IEEE Journal on Selected Areas in Communications, vol. 26, no. 9, pp. 1620-1627, December 2008, DOI: 10.1109/JSAC.2008.081202

[18] H. Chen et al., "Toward Long-Distance Underwater Wireless Optical Communication Based on A HighSensitivity Single Photon Avalanche Diode," in IEEE Photonics Journal, vol. 12, no. 3, pp. 1-10, June 2020, Art no. 7902510, doi: 10.1109/JPHOT.2020.2985205.

[19] M. Khalighi, C. Gabriel, T. Hamza, S. Bourennane, P. Léon, and V. Rigaud, "Underwater wireless optical communication; recent advances and remaining challenges," 2014 16th International Conference on Transparent Optical Networks (ICTON), Graz, 2014, pp. 1-4, DOI: 10.1109/ICTON.2014.6876673.