BER Performance of NLOS Underwater Wireless Optical Communication with Multiple Scattering

V K Jagadeesh, K V Naveen, P Muthuchidambaranathan

Abstract—Recently, there is a lot of interest in the field of under water optical wireless communication for short range because of its high bandwidth. But in most of the previous works line of sight propagation or single scattering of photons only considered. In practical case this is not applicable because of beam blockage in underwater and multiple scattering also occurred during the photons propagation through water. In this paper we consider a non-line of sight underwater wireless optical communication system with multiple scattering and examine the performance of the system using monte carlo simulation. The distribution scattering angle of photons are modeled by Henyey-Greenstein method. The average bit error rate is calculated using on-off keying modulation for different water types.

Keywords—Non line of sight under Water optical wireless communication, Henyey-Greenstein model, Multiple scattering, Monte-Carlo simulation.

I. Introduction

ALTHOUGH oceans and seas cover almost 70% of the earth's surface, information about them is limited. However, it is widely expected that oceans and seas have rich bio-diversity in the form of unique flora and fauna and huge amount of natural resources in the form of oil,sparse minerals etc. With the mankind already in search for new sources of essential resources, techniques for exploring oceans and seas should have significant scope in the near future. Hence, technologies for enabling underwater also have tremendous future relevance.

Underwater communication technologies will enable communication between divers, ships and submarines. The underwater sensor network (UWSN) also has wide range of application such as tsunami alerts, monitoring ecological changes and autonomous underwater vehicle operation(AUV) [1]–[3]. Usually radio frequency(RF) waves, acoustic waves and optical waves are using to transmit information in underwater communication. But RF waves cannot propagate through water because of high attenuation [4]. Acoustic communication is widely used technique in underwater because of its low attenuation. The main limitation of underwater acoustic link is low bandwidth because of its dependency on the frequency. Another problem is its low speed(1500m/s) in water leads a large time delay [5].

In recent years, underwater wireless optical communication(UWOC) found an alternative technology [6] for the traditional acoustic communication system for short range. The main problem here is the absorption and

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scattering [7] of optical beam from the water molecules and suspended particles in water when it propagates through water. The intensity of optical beam will be reduced due to absorption and there will be a deflection in the direction of propagation due to scattering. So UWOC links utilize the blue/green region of visible spectrum to transmit data due to lower absorption in this region [8]. The UWOC can provide high data rate, more security and lo time delay comparing with the traditional communication system.

In most of the previous works in this area considered single scattering and line sight (LOS) communication link only and attain data rate of 1Gbps over a few meters [6]. In coastal and harbor water the photons undergo multiple scattering. In [9] the author consider multiple scattering, but assumed LOS only. LOS communication link is not always possible in practical due to beam blockage by bubbles, fish or large suspended particles. A non-line of sight (NLOS) underwater communication link proposed in [10] and bit error rate (BER) performance is analyzed with single scattering. The effects of wind-generated random sea surface slopes and scattering characteristic of seawater and investigate the path loss performance of NLOS UWOC links in [11]. In this paper we consider a NLOS UWOC link with multiple scattering of photons. The BER performance is analyzed for different types of water using Monte carlo simulation method.

II. Underwater Channel Model

To characterize water and particulate material in water, several studies were conducted [12], [13]. When the optical beam propagating through water, the photons undergo absorption and scattering. These parameters are characterized using the coefficients $a(\lambda)$ and $b(\lambda)$ respectively [9]. Then the total attenuation is the sum of absorption and scattering and is given by

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

Here λ is the wavelength and the parameters are represented in m^{-1}.

Most of the previous works in UWOC link consider the LOS channel model and is modeled using simple Lambert's law with out scattering. The intensity of the optical beam at a distance z is given by

$$I(z) = I(0)exp(-c(\lambda)z) \tag{2}$$

Depending on the underwater material and water quality , four types of water is specified. They are

1. Pure sea water : Here absorption is more than scattering.

2. Clear ocean water: Here concentration of the dissolved particle is more and affects on scattering.

3. Coastal ocean water: Here concentration of planktonic matter, detritus, and mineral components that affect on both absorption and scattering.

4. Harbor water: Here concentration of dissolved and in-suspension matter are more and affect both scattering and absorption highly.

III. SIGNAL NOISES IN UNDERWATER

There are many sources of noise that disturb the optical communication system in underwater [14], [15]. These include both solar background noise and noise in the detector devices like PIN diode and avalanche photodiode. The background noise is negligible especially in deep sea water. So we have taken into consideration only noise due to detector device. This includes dark current noise, thermal noise and shot noise.

Dark current noise is present in photo diode. The variance of the dark current noise is given in [15]

$$\sigma_{DC}^2 = 2qI_{DC}B \tag{3}$$

where, q is the electron charge, $1.6*10^{-19}$C, $I_{DC} = 1.226*10^{-9}$A is the dark current and B is the electronic bandwidth.

Thermal noise (Johnson noise) is the dominant noise present in PIN diode [16]. Variance of the thermal noise is given [15] as

$$\sigma_{TH}^2 = \frac{4kT_eFB}{R_L} \tag{4}$$

where $k = 1.381 * 10^{-23}$J/K is the Boltzman's constant, $T_e = 290$K is the equivalent temperature, $F = 4$ is the noise figure of the system and $R_L = 100\Omega$ is the load resistance. Shot noise is the dominant noise in APD [16] and the variance of the current shot noise is given by [15]

$$\sigma_{ss}^2 = 2q\Re P_sB \tag{5}$$

where $\Re$ is the responsivity in Amps/watt and P_s is the signal power in watt.

IV. MODELLING OF NLOS PROPAGATION

For modeling NLOS propagation, the approach used in [17] is followed. i.e, the multiple scattering process is simulated as several successive single scattering. Here the Monte Carlo method is used to simulate the model. The basic NLOS system model is shown in Fig. 1. The transmitter and receiver are represented as two triangles separated by a distance 'r'. The figure shows only single scattering of photon on interaction with a particle in water. The process start by initializing the system parameters shown in Fig. 1.

A. Initialization

The Cartesian coordinates $(x; y; z)$, polar and azimuthal angles (θ and ϕ respectively) are considered to follow the trajectories of photons. Initially, the transmitter and receiver are positioned as shown in Fig.1. Here $\alpha1$ and $\alpha2$ indicates transmitter and receiver elevation angles. $\beta1$ indicates maximum initial divergence and $\beta2$ indicates the receiver field-of-view (FOV).
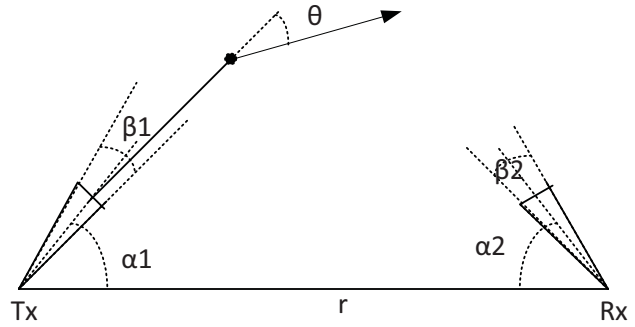

Fig. 1. NLOS underwater communication link

The simulation is begun by sending a photon into the water. Each photons initial direction must be confined within the full beam angle $\beta1$ with solid angle $2\pi(1 - cos(\beta1/2))$. The light source is placed in the coordinate system such that the beam axis has a polar angle $(\pi/2 - \alpha1)$ and azimuth angle 0°. Denote the initial direction of an individual photon with respect to the polar angle as θ_{ini} and with respect to the azimuth angle as ϕ_{ini}. ϕ_{ini} is an uniform random variable between 0 and 2π and is given as

$$\phi_{ini} = 2\pi\xi^\phi \tag{6}$$

where, ξ^ϕ is an independent random variable which is uniformly distributed between 0 and 1. θini is taken as a random angle uniformly distributed between $[\alpha1 - \beta1/2, \alpha1 + \beta1/2]$.

B. Interaction of Photon with Particle

The photon, on propagation through water will interact with different particles. Each photon travels a random distance, Δs (step size) before interaction with any particle. To generate Δs randomly, an uniform random variable, ξ^s between zero and one is considered. Then

$$\Delta s = -\frac{log(\xi^s)}{c(\lambda)} \tag{7}$$

To model absorption, an unit initial weight, W_{pre} is considered for each photon. Now, upon each interaction, the photon will loose some weight with new weight W_{post} and is obtained as

$$W_{post} = (1 - a/c)W_{pre} \tag{8}$$

Direction cosines is used to determine the new spatial position of the photon after each interaction [17]. To model the scattering, the generalized Henyey-Greenstein function [18] is used.

$$P_{HG}(\theta, g) = \frac{1 - g^2}{2 * (1 + g^2 - 2gcos\theta)^{3/2}} \tag{9}$$

with g being the HG asymmetry parameter that depends on the characteristics of the medium and is expressed as the average cosine of the scattering angle θ over all scattering directions as in [9]. To generate a random polar angle θ, first generate a RV ξ of uniform distribution between 0 and π

Water Type	$a(\lambda)(m^{-1})$	$b(\lambda)(m^{-1})$	$c(\lambda)(m^{-1})$
Pure sea water	0.053	0.003	0.056
Clear ocean water	0.069	0.08	0.15
Coastal water	0.088	0.216	0.305
Turbid water	0.295	1.875	2.17

and then calculate the corresponding θ using the following equation

$$\chi_{HG} = \int_0^\theta p_{HG}(\Psi, g) sin\Psi d\Psi \qquad (10)$$

From the above equation the θ can be calculated as

$$cos\theta = \frac{1}{2g}\left[1 + g^2 - \left(\frac{1 - g^2}{1 - g + 2g\chi_{HG}}\right)^2\right] \qquad (11)$$

The newly generated azimuthal angle ϕ is given as

$$\phi = 2\pi\xi^\phi \qquad (12)$$

Thus, the new propagation direction of the photon (i.e.,the new θ and ϕ) is determined after each interaction with a particle [17].

C. Photon Propagation through Water

Water contains various types of particles in solution and suspension. So, when photon propagates through water, it will interact with several particles each time undergoing absorption and scattering. Photons undergo both forward and backward scattering. Here forward scattering only considered as those only mostly contribute for data transmission.

D. Photon Reception

The process of simulating of each photon will continue until it is received at the photo detector or photon becomes useless. Photon is properly received if it reaches the receiver plane within the receiver FOV. Photon becomes useless when it's weight goes below a threshold or the photon is not within the FOV of the receiver. The threshold weight for photon survival is taken as 10^{-4}.

V. SIMULATION RESULTS AND DISCUSSION

In this work, three different water types are considered as mentioned in section II and compared the BER against transmission distances for LOS and NLOS models for each water type. Values for absorption, scattering and attenuation coefficients for the three water types [9] are shown in the table 1. Simple OOK modulation without any error correcting coding is used. The transmitter parameters are set as wavelength $532nm$ and maximum initial divergence angle 20° and HG asymmetry parameter g is set as 0.924 [18]. For the NLOS model, the geometric parameters $\alpha1$, $\alpha2$, $\beta1$ and $\beta2$ are taken as 10°, 30°, 60° and 60° respectively. The input data consists of a stream of ones. For each bit $'1'$, we transmit 2000 photons with the trajectory of each photon traced as explained.
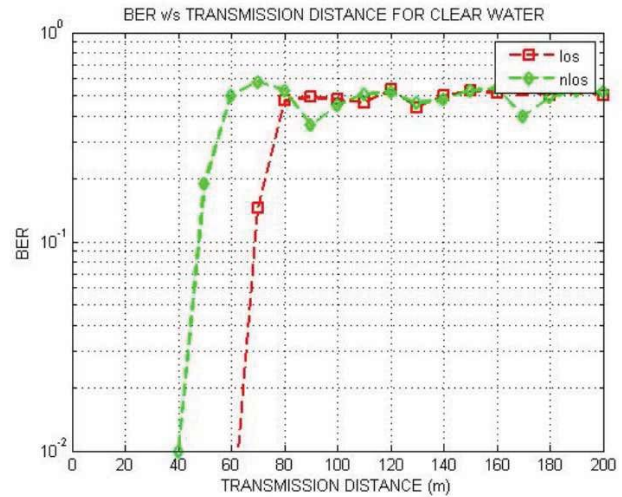

Fig. 2. BER against transmission distance for clear water

Fig. 2 shows the BER performance of clear ocean water against transmission distance. From the figure it is observed that LOS model achieves a transmission range of 70m while NLOS achieves 50m for a BER of 10^{-2}. Fig. 3 depicts BER against transmission distance for pure sea water. Here the LOS model achieves a transmission range of 80m and NLOS achieves 55m for a BER of 10^{-2}. In Fig. 4 the BER performance of coastal ocean water is analyzed. From the graph we can see that The LOS model has a range of 40m and NLOS model has a range of 30m for a BER of 10^{-2}.

Thus, the comparison shows that LOS model achieves more range than NLOS for a specified BER. Also, we can see that transmission distance decreases steadily from pure sea water to clear ocean water to costal ocean water. This is correct as the attenuation coefficient is more for costal, followed by clear ocean and least for pure sea water.
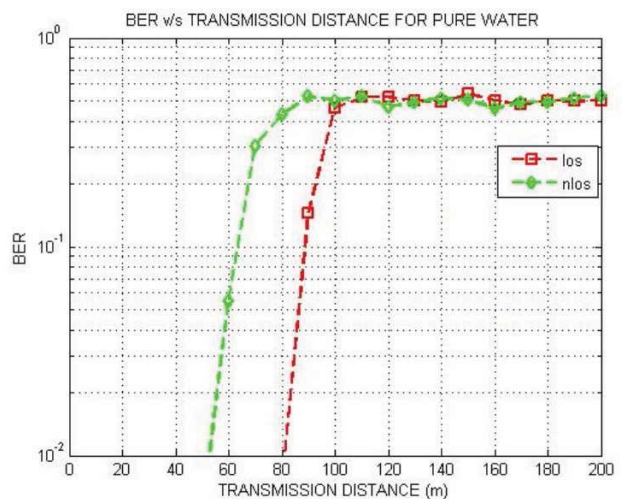

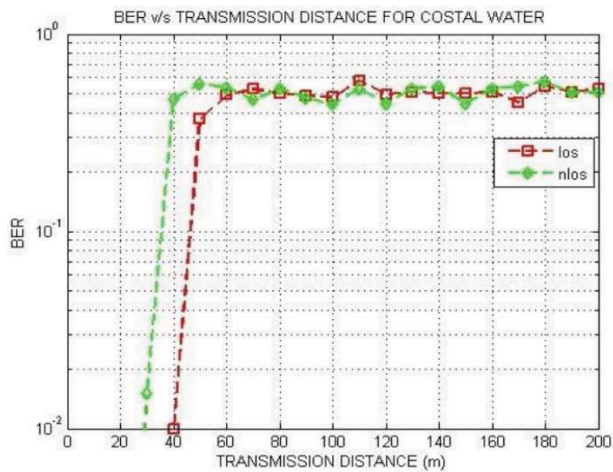Fig. 3. BER against transmission distance for pure water

Fig. 4. BER against transmission distance for coastal water

VI. CONCLUSION

In this paper, NLOS underwater optical wireless communication system based on multiple scattering of photos is proposed on different types of water such as pure, clear and coastal. Unless in the conventional systems, we dealt with multiple scattering models for NLOS propagation. Also the distance traveled by photos in each types of water is compared in terms of BER for LOS and NLOS models. As can be expected the NLOS has less transmission range compared to LOS for a specific BER. The perfectly aligned LOS model is always not possible in practical due to beam blockage caused by bubbles , fish or large suspended particles. So this work is an important phase, based on which NLOS underwater wireless communication can be proceed.

REFERENCES

[1] J. Heidemann, W. Ye, J. Wills, A. Syed, and Y. Li,. "Research challenges and applications for underwater sensornetworking". In *Proceedings of IEEE WirelessCommunications and Networking Conference, WCNC.*, 2006, p. 228 - 235.
[2] S. Arnon, "Underwater optical wireless communication network", *Opt. Eng.*, vol. 49, no. 1, pp. 1-6, Jan. 2010
[3] D. Anguita, D. Brizzolara, and G. Parodi, "Building an under-water wireless sensor network based on optical communication:Research challenges and current results", In *Int. Conf. on Sensor Technologies and Applications (SENSORCOMM)*, Athens,Greece, Aug. 2009, pp. 476-479
[4] B. M. Cochenour, L. J. Mullen, and A. E. Laux, "Characterization of the beam-spread function for underwater wireless optical communications links", In *IEEE J. Ocean. Eng.*, vol. 33, no. 4, pp. 513-521, Oct. 2008.
[5] G. Shah, "A survey on medium access control in underwater acoustic sensor networks", In *Int. Conf. Workshops on Advanced Information Networking and Applications (WAINA)*, Bradford,UK, May 2009, pp. 1178-1183
[6] F. Hanson and S. Radic, "High bandwidth underwater optical communication", In *Appl. Opt.*, vol. 47, no. 2, pp. 277-283, Jan.2008.
[7] C. F. Bohren and D. R. Huffman, "Absorption and Scattering of Light by Small Particles", In *Wiley*, 1988.
[8] K. S. Shifrin, "Physical Optics of Ocean Water", In *American Institute of Physics*, New York, 1988.
[9] Chadi Gabriel, Mohammad-Ali Khalighi, Salah Bourennane, Pierre Lon, and Vincent Rigaud, "Monte-Carlo-Based Channel Characterization for Underwater Optical Communication Systems", In *Journal of Optical Communications and Networking*, Vol. 5, Issue 1, pp. 1-12 , Jan.2013.
[10] S. Arnon and D. Kedar, "Non-line-of-sight underwater optical wireless communication network", In *J. Opt. Soc. Am. A 263*, 530-539.
[11] Tang, Shijian; Dong, Yuhan; Zhang, Xuedan, "Impulse Response Modeling for Underwater Wireless Optical Communication Links", In *IEEE Transactions on Communications*, Vol. 62, Issue 1, pp. 226-234 , Jan.2014
[12] J. H. Smart, "Underwater optical communications systems. Part1: Variability of water optical parameters", In *IEEE Military Communications Conf.*, Atlantic City, NJ, Oct. 2005, vol. 2, pp. 1140-1146.
[13] R. P. Bukata, J. H. Jerome, K. Y. Kondratyev, and D. V. Pozdnyakov, "Optical Properties and Remote Sensing of Inland and Coastal Waters", In *CRC Press*, Boca Raton, FL 1995.
[14] J. W. Giles and I. Bankman, "Underwater opticalcommunication systems. Part 2: Basic design considerations", In *IEEE Military Communications Conf. (MILCOM)*, Atlantic City, NJ, Oct. 2005,vol. 3, pp. 1700-1705.
[15] S. Jaruwatanadilok, "Underwater wireless optical communication channel modeling and performance evaluation using vector radiative transfer theory", In *IEEE J. Sel. Areas Commun.*, vol. 26, no. 9, pp. 1620-1627, Dec. 2008.
[16] F. Xu, M. A. Khalighi, and S. Bourennane, "Impact of different noise sources on the performance of PIN- and APD-based FSO receivers", In *COST IC0802 Workshop, IEEE ConTEL Conf.*, Graz, Austria, June 2011, pp. 279-286.
[17] H. Ding, G. Chen, A. K. Majumdar, B. M. Sadler, andZ. Xu, "Modeling of non-line-of-sight ultraviolet scatteringchannels for communication", In *IEEE Journal on Selected Areasin Communications*, vol. 27, no. 9, pp. 1535-1544, 2009
[18] C. D. Mobley, "Light and Water: Radiative Transfer in Natural Waters". In *Academic Press*, June 1994.

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