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Oceanic Turbulence and Beam Propagation Characteristics of Underwater Optical Wireless Communication: A Brief Survey

J.M. Aravind¹, Y.P. Arul Teen²

¹Department of ECE Mar Ephraem college of Engineering and Technology Tamil Nadu, India. jamesaravind@gmail.com

²Department of ECE University College of Engineering Tamil Nadu, India
E-mail: arulteen@yahoo.co.in

ABSTRACT

Underwater wireless communication (UWC) means the transmission of information using wireless channels through the underwater, i.e. radio frequency waves (RF), acoustic waves and optical waves in an unguided water environment. In this review article we focus on underwater optical wireless communications (UWOCs) using optical waves as transmission medium. UWOCs have a much higher communication frequency and therefore a much higher data rate compared to RF and acoustic counter-parts. Due to this high-speed data transfer advantage, UWOC has been very attractive over the past few years. Many application have been proposed in UWOC systems for protection of the environment, underwater exploration, emergency alerts and military operations etc. However, underwater absorption, scattering and turbulence processes will introduce attenuation and fading to light propagation and then degrade the performance of underwater wireless optical communications (UWOC). In this review paper we give a detailed overview of turbulence and beam propagation characteristics of different water bodies in UWOC.

Index Terms: Underwater Wireless Optical Communication, UWOC, Turbulence, and Beam Propagation.

1 Introduction

In the last few years, the interest towards optical wireless communication has increased for terrestrial, space and underwater links as it is capable of providing high data rates with low power and mass requirement. Many of researchers have carried out work for terrestrial and space links [1]–[6], however underwater optical wireless links are relatively less explored as it is more challenging than atmospheric links. The significant hurdle for reliable underwater communication is due to wide range of physical processes in various types of underwater environments ranging from shallow coastal water to deep sea or oceans. Usually, underwater wireless communication takes place via acoustic waves due to their relatively low attenuation, but unfortunately, acoustic systems have low bandwidth and high latency. Therefore, they are not suitable for applications that require data-intensive information exchange in real time. However, since acoustic communication is the only technology that



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transfers information for long distances, broad studies are continuously conducted to get better performance of the acoustic communication channels [4-6]. Besides, acoustic underwater communication is susceptible to malicious attacks [7]. So, complementary technology for achieving secure broadband underwater communications is required. Wireless communication via radio frequency (RF) waves is the popular widespread technology in terrestrial communications. Unfortunately, this technology is not suitable for underwater use since the radio frequency waves are strongly attenuated in water medium. 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 being used. It has been observed that attenuation of RF waves increases with the increase in frequency and are heavily attenuated by sea water.

Under water wireless Optical communication, on the other hand, has gained more and more recognition with its high scalability and versatility. Over the past years, UWOC has gained tremendous attention in both academic and business communities with the benefits of ample bandwidth, high reliability, and small foot-print and low latency. Underwater Wireless Communication Technology, UWOC provides many interesting choices for a variety of short-distance bandwidth-intensive applications to supplement the more developed acoustic connection. The theoretical performance of different underwater communication technologies (UWC) based on bandwidth and range of communication [7], [8], [9], [10] is shown in Fig. 1 the overall comparison of three UWC technologies is shown in Table I.

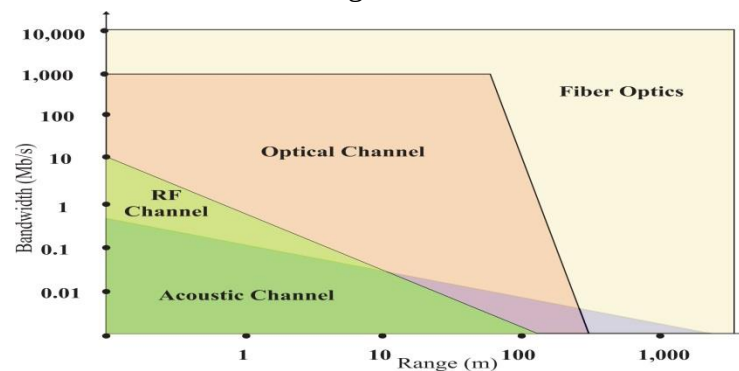


Figure 1: Comparison of Bandwidths of Various UWC Channels [7], [8], [9]

Table 1: Comparison of various UWC technologies

UWC	Benefits	Limitations
Acoustic	- Widely used UWC technology. - The range of communication is long.	- Low data transfer rate (only in kbps order). - Transceivers that are bulky, costly and consumes more energy. - Hazardous to marine life.



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RF	- Pretty smooth transformation to water/air boundaries. - Extremely tolerant to turbulence and turbidity of the water. - Loose pointing requirements. - The data transfer rate is modest (up to 100Mb/s) at a very small distance	- Limited range of connections. - Transceivers are bulky, expensive and consumes are energy.
Optical	- Ultra-high-speed optical data transmission (up to Gbps) - Immune to latency during transmission. - Low cost, limited volume transceivers.	- Cannot easily exceed water/air limits. - Suffers from strong absorption and Propagation. - The range of the connection is moderate (up to several tens of meters).

Typically, fast and secure connectivity is provided by wired or fiber-based technology. Nevertheless, its use can be challenging in areas with difficult access and deep waters, as it limits the range and control ability of underwater vehicles. In these situations, wireless networking methods are of great importance. The large available bandwidth enables optical networks to deliver unprecedented high data rates (from Mbps to Gbps) over short and medium ranges (typically up to several decades of meters) [11]. In addition, optical transmission is generally not delayed due to the high speed of propagation of optical waves in water. Optical communication is therefore a desirable alternative to acoustic remote communication [12].

UWOC was also proposed to meet a number of specifications for different underwater applications [13] due to its scalability, robustness and functionality. Optical transmission is of higher bandwidth. UWOC is therefore considered a strong alternative for underwater high-speed communications and high data transmission requirements such as images, real-time video transmission, high-performance sensor networks, etc. [14]. Nevertheless, because of the extreme degradation effects of the UWOC channel, i.e. absorption, dispersion and turbulence etc., UWOC is only suitable for short-range (about 100 m) communication with a practical average transmission power [13]. UWOC shall include a more comprehensive analysis of the essence of these degrading effects and intelligent methods of transmission, reception and system design. Fig. 3 demonstrates a basic block diagram for underwater communication. It shows the relation between the source, the transmitter, the transmitter, the receiver and the information received at the destination. The channel here is sea that is salt water. The scope of this investigation is to present a wide range of challenges and technologies currently being used in.

2 Review on turbulence and Beam Propagation

Dong et al [16] considered UWOC MISO compounds illuminated by UCA any number of light sources. Additionally, the authors extracted the BER term at high turbulence as well as



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absorption and dispersion. Numerical results indicate that turbulence may degrade the performance of BER... The passive time reversal technique was modeled for the underwater channel [17] to reduce the multipath effect. The multi-hop transmission is considered in [18] by an optically turbulent underwater channel. Maximum Ratio Combining (MRC) Spatial Diversity Technique was developed to improve the bit rate performance of the UWAC (underwater acoustic communication) receiver system [19]. The new optical front- end for free space submarine communication introduces the concept of smart transmitters and receivers as proposed in [20].

The UOWC channel is characterized by both scattering/absorption and UOT, and a SIMO scheme to attenuate the deeply faded turbulence channel was proposed in [21]. The mathematical modeling and performance evaluation of the UWOC channel was presented in [22]. In [23], a new nonlinear UWOC network was proposed, based on an inverse reflection of the propagation of the optical signal at the ocean- air interface. In [24] NLOS proposed an underwater wireless optical communication system based on the distribution of several photons for different water species. A laser diode system based on optical wireless submarine communication (UWOC) is shown in [25]. The temporal dispersion of UWOC bonds in turbid environments is investigated in [26] due to multiple dispersion effects.

The impact of system performance as well as recent developments in the characterization of UOWC channels, modulation schemes, code techniques and various UOWC-specific noise sources are discussed in [12]. Random variations in the underwater medium are mainly due to temperature and salinity variations, while variations in the atmosphere are due to homogenization of temperature and pressure changes [27]. Detection techniques known as MLSD are presented in

[28] For open space optical communication systems. Optical communication is demonstrated at 1 Gbit / s through a 2 m long water pipe upwards with an extinction of narrow beam up to 36 dB [29]. The usage and reliability of UWOC systems has been tested by using error correction codes [30].

Spatial diversity is a major improvement in performance, but an autonomous link is established in [31] which can sometimes be virtually infeasible. An exhaustive understanding of UWOC channel characteristics and various related factors limiting UWOC systems performance is discussed [32]. As the water turbidity increases the water absorption, losses also increase at the reception end. This reduces the data rate and leads to ineffective communication in turbid port water [33]. Several studies investigated the effects of turbulence, but ignored the effects of dispersion and ISI and used freely spatially optically (FSO) typical conditions of BER [34]. In [35], a hybrid solution for both acoustic and optical communication was examined in order to ensure that mobile sensor system scan transmit video in real time. In [36] a true UWO channel model is presented using a sophisticated Monte Carlo Simulator which takes into consideration the diverse transmission parameters,



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such as the type of water and the features of the transmitter / receivers. In [37], there is a MIMO-OFDM system of spatial multiplexing. In [38], there is an adaptive and iterative SPRE system for UWA shallow water channels together with a jointly optimized phase tracking loop. Table II shows the summary of the above.

Author and Year	Algorithm /Technique used	Result	Findings
Donget.al.2016[16]	UWOCMISO With UCA	BER performance may be affected by turbulence	The spatial transmission diversity of the UWOCMISO system can reduce performance gradation.
Murugan.et.al.2016[17]	Simulate UAC in 120m deep water using the PTR technology with transmitter and receiver in range of 4km	The optimum range other receiver elements for efficient contact is 16-32, while the optimum separation distance for the two users is 10m.	BER of approximately 10^{-2} is obtained for single user and approximately 10^{-2} for multi user for TRM of the 32 elements.
Pranitha.et.al.2016.[19]	OFD Misused nan UWAC	The number of antennas obtained increases in the receiver and the BER decreases.	A better way to booster roar efficiency is to enhance spatial diversity along with the MRC.
Simpson et.al.2012[20]	The portable and intelligent transmitters and receivers have been demonstrated for free space under water optical communication	Mitigates criteria for pointing and tracking which may be difficult for underwater platforms and all low adaptive communication technologies to be introduced.	Implementations Such as those submitted in conjunction with CDMA and other coding methods would be helpful to allow for physical networking in the future in unmanned under water swarms.
Liu et.al. 2015[21]	Statistical simulation system based in Monte Carlo	Minimize the extreme fading of turbulence channel	The LED with 1 W optical power may use the SIMO system to communicate in a powerful UOT channel effectively over 60m.



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Jagadees het.al.20 15 [24]	NLOS UWOC is proposed on the basis of multiple photoles dispersion.	In contrast to LOS for a particular BER, NLOS has a transmission range.	Clear ocean water the LOS model reaches a maximum of 70m, while the NLOS reaches 50m for BER value of 10 ⁻² . Pure sea water the LOS model is 80m long and the NLOS reaches 55m for a BER value of 10 ⁻² .
FrankHa nson1 and Stojan Radic 2008 [29]	Validated optical communication at 1Gbit/s through a 2m pipe with a narrow beam extinguishing of up to 36dB.	From MonteCarlo data, a frequency response of the medium of propagation was determined. The data rate was restricted by the detector of 1GHz.APD.	Across a variety of ocean water conditions, the intrinsic band width is sufficiently high to have data levels of 1Gbit/s for reasonable ranges.
Abou R jeilyand AhmadS lim.2011 [31]	Cooperative diversity scheme with one relay	Important improvements in non-Cooperative 1to1 FSO connection sand over 2to1 MIMO-FSO links with correlated fading.	Analytically, no case of back ground radiation has shown that a complete diversity order can be achieved. Retention of acceptable power gains, especially with back ground radiation in the case of Rayleigh fading.
Hemani Kaushal andGeor gesKadd oum,201 6.[12]	Hybrid optical-acoustic system.	Strong data speeds, low latency and good energy efficiency.	The present acoustic system is replaced by a hybrid acousto-optic system.
S.Arnon andD.Ke dar,2009 [23]	ALOS and NLOS model for counting the maximum probability of biterrorina under water sensor network.	The networks of underwater sensors with laser communications are feasible for mobile wireless users with high data rates of up to 100m medium distance.	For the NLOS reflective link, BER values of 10 ⁻⁴ are obtained when the separation between nodes is 40m, while in a LOS connection a BER of 10 ⁻⁴ may be achieved when the separation between nodes is 60m.



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Zhaoquan Zeng et al. 2016 [32]	Hybrid acoustic/UWOC systems	A detailed understanding of UWOC channel features and various related factors restricting the efficiency of UWOC systems.	Compared to FSO Communication, UWOC is much less researched and a viable technology for wireless communication in the presence of hostile channels.
Kumar et al. 2011 [33]	LOS, Retro Reflector Modulation Link and Reflective Link scenarios were compared.	Using the optical Transceiver, the hybrid communication device will provide high data rate transmission.	The line of sight scenario is most efficient than modulating retro reflector link and reflective link.
H. Gercekcioglu et al. 2014 [34]	For horizontal optical links, Gaussian beam in low ocean turbulence are constructed using the Rytov method	BER decreases With increasing rates of turbulent kinetic energy dissipation per unit mass of fluid. As the average squared refractive index fluctuation rate decreases, BER decreases.	The increase in the size of the source at fixed SNR results in an improvement in BER for collimated Gaussian beams and a drop in BER for Gaussian beams.
S.J. Dilok et al. 2008 [22]	Modeling of Underwater communication channels using vector radiative transfer theory.	The bit error rate decreases as expected as the distance increases.	Owing to a bit rate and field of view, the distance at that the data transmission can be predicted.
Chao Shen et al. 2016 [25]	The LD based UWOC system with a data rate of 1.5 Gbps was demonstrated over a 20-meter underwater channel on the NRZ-OOK basis.	Enhanced range of transmission.	BER were successfully achieved for a data rate of up to 2 Gbps for a 9-meter and a 12-meter UWOC Link.
V. Shijian Tang, Yuhan Dong,	Modeling of Impulse response for UWOC.	ISI greatly degrades BER output without equalization for high bit rate systems.	Equalization of ZF improves BER efficiency.



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and Xuedan Zhang,2 014.[26]			
S.Mohamed Nadim vidpou t.al.2007 [27]	Performance study of error rate and free space optical communication.	A reduction of channel variance, the impact of spatial diversity many fests	The loss of performance due to spatial correlation could be significant. Efficient separation between apertures and strict Co-alignment are essential to achieve the expected diversity gains from multiple transmit-terms/receivers.
Xiaomin gZhuand JosephM .Kahn,20 06[28]	MLSD (maximum likelihood sequence detection)	To increase detection efficiency, it is possible to use ML symbols when the immediate fading is unknown but the marginal fading statistics are known, and MLSD scan be used when turbulence-induced fading is a common temporal distribution.	The reception of ML diversity out performs the traditional EGC system.
Hamza Gerçekci oğlu.201 4 [39]	Scintillation index for horizontal optics links by using the Rytov method.	A focused Gaussian beam having a large source size seems to attain the lowest scintillations at all propagation distances.	For both collimated and focused Gaussian beams, at a fixed SNR, BER decreases when the rate of dissipation of turbulent kinetic energy per unit mass of fluid ϵ increase
Frank Hanson, 2010[40]	Collimated flat-top and Gaussian laser beams were propagated through the water path	The importance of beam size relative to the transverse coherence length	The degrading effects of turbulence on underwater propagation are reduced for smaller beams
Wei Lu.2006.	The behavior of PCBs propagating through oceanic turbulence	For a particular water volume the ratio of the temperature gradient to that of salinity is	Beams with weaker coherence have wider spreading and a longer



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[41]		fixed,	turbulence distance than their counterparts with stronger coherence.
N. Farwell. 2012[42]	Spectrum of refractive index fluctuations of the second order statistics of a Gaussian beam propagating in clear-water oceanic turbulence.	Using both on-axis and off-axis analysis the r.m.s. widths of intensity distribution and of the degree of coherence for any distance from the axis are calculated correctly.	The effect of optical turbulence on the intensity of such a beam can be significant as compared to that of absorption for specific wavelengths
Miaomia Tang. 2013[43]	The propagation properties of a radially polarized beam through a turbulent ocean based on the extended Huygens–Fresnel principle	Beam propagation in the oceanic turbulence show that the beam quality will be destroyed by the oceanic turbulence.	Radially polarized beam propagating in oceanic turbulence changes its beam profile into a Gaussian beam profile as the propagation distance z increases.

3 Conclusion

In this paper, we have concluded by performing a short survey regarding the features of UOWC and the challenges faced. Among various challenges, turbulence is found to be the most challenging one. The above literature shows that the performance of UOWC due to oceanic turbulence and beam Propagation by spatial diversity scheme and beam forming schemes and number of diversity branches increases the performance. A turbulent atmosphere contains various aberrations. Different types of aberrations and their effect on Gaussian beam, LG beam, and BG beam were studied, and these studies show that tilt aberration has more impact on laser beam propagation through turbulent atmosphere. In the future it is planned to find out the effect of various aberrations on Hyper-geometric and Ince-Gaussian laser beam profiles.

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