Research Journal of Applied Sciences, Engineering and Technology 8(7): 844-849, 2014
DOI:10.19026/rjaset.8.1043
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: May 09, 2014 Accepted: June 13, 2014 Published: August 20, 2014

Research Article

Feasibility Study of High Data Rate Underwater Optical Wireless Network

V. Reji, T. Beula Chitra Priya and G. Revathi
Department of ECE, SRM University, Chennai, India

Abstract: The present technology of acoustic underwater communication is a legacy of technology that provides low data rate transmission for medium range communication. In addition the speed of acoustic waves in the ocean is approximately 1500 m/sec so that long range communication involves high latency which poses a problem for a real time response and synchronization. In addition acoustic waves could distress marine mammals such as dolphins and whales. So the acoustic technology needs high data rate communication networks in real time. The growing need for underwater observation and subsea monitoring systems has stimulated considerable interest in advancing the enabling technologies of underwater wireless communication and underwater sensor networks. This communication technology is expected to play an important role in investigating climate change, in monitoring biological, biogeochemical, evolutionary and ecological changes in the sea, ocean and lake environments and in helping to control and maintain oil production facilities and harbours using unmanned underwater vehicles UUVs, submarines, ships, buoys and divers.

Keywords: BER, channel, datarate, link, LOS, noise

INTRODUCTION

Underwater optical communications are being considered for a verity of applications in littoral waters. Application such as communications among underwater platforms can be Unmanned Underwater Vehicles (UUVs), submarines, ships, Buoys, Docking stations, underwater sensors, autonomous, robotic vehicles and Divers (Shlomi, 2010). Example of such applications is network of sensors for the investigation of climate change monitoring biological and biogeochemical and ecological process in sea. Additionally a group of small UUVs acting together may require a high BW communication system to coordinate the actions of the vehicles.

Traditionally wireless under water data communication employs acoustic waves. Because sound propagates well in water may provide suitable underwater communication. However the maximum data transmission rates of these systems in shallow littoral waters are approximately 10 kbytes/sec Kbps which may be achieved only at ranges of less than 100 m (Shlomi, 2010). The acoustic communication channel has less bandwidth, therefore it can only handle a relatively low bit rate. Acoustic wave speed in water is slow (1500 m/sec), it creates problem for real time response and Synchronization. In addition acoustic signal could distress marine mammals such as dolphins and whales. RF signal also highly attenuated by sea water. To accommodate a higher bit rate a higher frequency has to be considered. A possible solution of this is optical frequency.

Link models: We now consider three types of communication links: the line of sight, the modulating retro-reflector and the reflective. In addition, we perform a bit error rate BER calculation. It is clear that an increase in the turbidity dramatically increases the extinction coefficient, from less than 0.1 m^{-1} for pure water up to more than 2 m^{-1} for turbid harbour water (Jaruwatanadilok, 2008). However, the absorption coefficient increases more moderately than does the turbidity. The propagation loss factor as a function of wavelength and distance z is given by:

$$L = \exp(-c\, z)$$

Line-of-sight communication link: The most common link between two points in optical wire-less communication systems is a line-of-sight LOS link as illustrated in Fig. 1. In this scenario, the transmitter directs the light beam in the direction of the receiver. The optical signal reaching the receiver is obtained by multiplying the transmitter power, telescope gain and losses and is given by:

$$P_{Rlos} = P_T\, \eta_T \eta_R\, L_{pr}(\lambda, d/\cos\theta)\, A_{rec} \cos\theta / 2\pi d^2 (1-\cos\theta_o)$$

where,

η_T = Optical efficiency of the transmitter
η_R = Optical efficiency of the receiver

Corresponding Author: V. Reji, Department of ECE, SRM University, Chennai, India

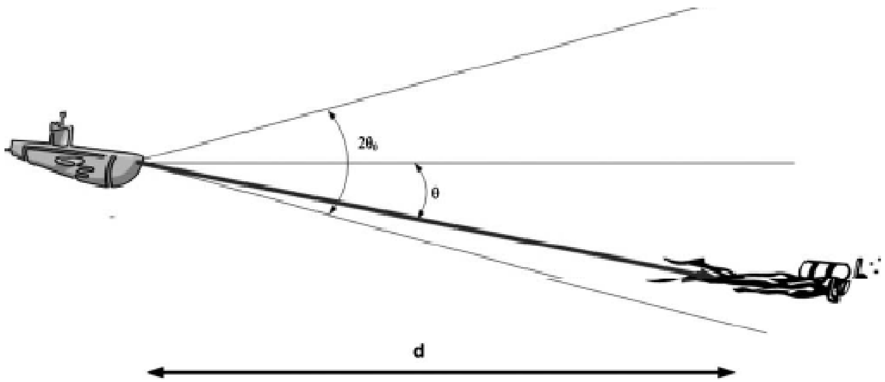


Fig. 1: LOS link

d = The perpendicular distance between the Tx and Rx
θ = The angle between the perpendicular to the receiver plane Receiver trajectory
P_T = The average transmitter optical power and the transmitter

Reflective communication: In some communication scenario the line of sight is not available due to obstructions, misalignment, or random orientation of the transceivers (Duntley, 1971). To address this problem a reflective communication link could be used. In this case, the laser transmitter emits a cone of light defined by inner and outer angle θ_{min} and θ_{max} in the upward direction (Cochenour *et al.*, 2008) the light reaching the ocean air surface illuminates an angular area and is partially bounced back in accordance with the reflectivity. Since the refractive index of air is lower than that of water, Total Internal Reflection (TIR) can be achieved above a critical incidence angle. When the transmitter is at depth h, the illuminated angular surface with equal power density at depth x is given by:

$$A_{nn} = 2\pi\ (l + x)^2\ (1 - \cos\theta_{max} - 1 + \cos\theta_{min})$$

$$A_{nn} = 2\pi\ (l + x)^2\ (\cos\theta_{max} - \cos\theta_{min})$$

Equation describes an annular area taken from a sphere of radius l+x which would have uniform power density in free space. If we model the ocean air surface as smooth then $\theta = \theta_i$ and we can derive the link budget by using the variable defined in LOS. Then we can define the auxiliary function and calculate the received power as:

$$f_{R\_ref}(\theta) = P_T\cos\theta/A_{nn}\ [\eta_T\eta_R L_{pr}\ (\lambda,\ (l + x)\ /\cos\theta)\ 1/2\ \{[\tan\ (\theta_i\text{-}\theta)\ /\tan\ (\theta_i + \theta)]^2 + [\sin\ (\theta - \theta_i)\ /\sin\ (\theta + \theta i)]$$

When $\theta_{min}\text{-}\theta<\theta_c$
Or,

$$f_{R\_ref}(\theta) = P_T\cos\theta/A_{nn}\ [\eta_T\eta_R L_{pr}\ (\lambda,\ (l + x)\ /\cos\theta)]$$

When $\theta_c \le \theta < \theta_{min}$

At the plane of the receiving sensor, node coverage is provided with in an angular area bounded by radii (l+x) tan θ_{min} and (l+x) tanθ_{max} now the above equation can be simplified on the assumption that the receiver aperture is small relative to (l+x) yielding the approximate received power as:

$$P_{ref}\ (\theta) = A_{rec}\ f_{R\_ref}\ (\theta)$$

Modulating retro-reflector link: The modulating retro-reflector link is used when one party (for example a submarine) has more resources another one (for example a diver) as shown in Fig. 2. In this case submarine has more energy, pay load and lifting capacity than the diver (Arnon and Kedar, 2009; Zege *et al.*, 1991). Therefore it would be wise to put most of the complexity and power requirement of the communication system in to the submarine. In a modulating retro-reflector link, the interrogator sits at one end and the small modulating retro-reflector sits at the remote end. In operation the interrogator illuminates the retro-reflecting end of the link with a continuous wave beam. The retro-reflector inactively reflects this beam back to the interrogator while modulating the information on it. The received power in this scenario is given by:

$$P_{Rlos} = P_T\eta_T\eta_{Rec}\eta_{Retro}L_{pr}\ (\lambda,\ 2d/\cos\theta)\ [A_{Retro}\ \cos\theta/2\pi d^2\ (1 - \cos\theta_o)] \times [A_{rec}\cos\theta/\pi\ (d\tan\theta_{oretro})^2]$$

where,
η_{Retro} = The optical efficiency of the retro-reflector
θ = The angle between the perpendicular to the receiver plane and the transmitter-receiver trajectory
A_{Retro} = The retro-reflector's aperture area
θ_{oretro} = The retro reflector's beam divergence angle

Attenuation in optical wireless communication channel: Light pulses propagating in aquatic medium Suffer from attenuation and broadening in the spatial, angular, tempo-real and polarization domains. The

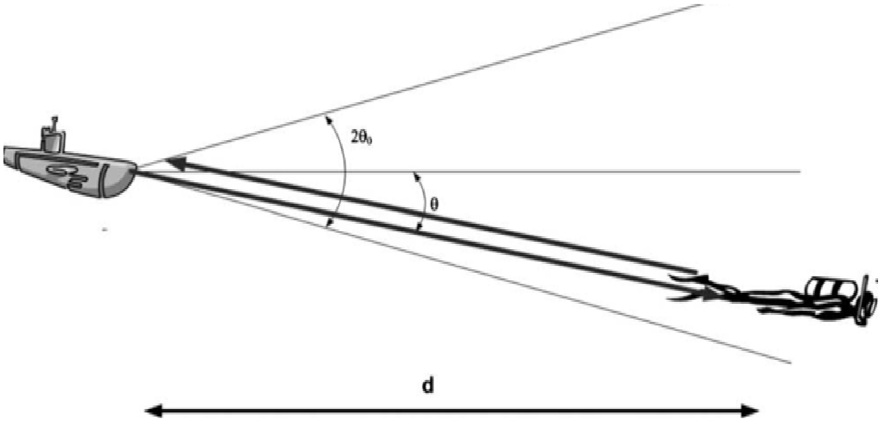


Fig. 2: The modulating retro-reflector communication

attenuation and broadening are wavelength dependent and result from absorption and multi scattering of light by water molecules and by marine hydrosols mineral and organic matter. The extinction coefficient c of the aquatic medium is given by the absorption and scattering coefficients and respectively:

$$C(\lambda) = a(\lambda) + b(\lambda)$$

RESULTS AND DISCUSSION

The most common figure of merit for digital links is the bit error rate, which commonly is abbreviated as BER. This is defined as the number of bit errors N_E occurring over a specific time interval, divided by the total number of bits N_T send during that interval; that is, BER = N_E/N_T. The error rate is expressed by a number, such as 10^{-9}. The simplest and most wide spread modulation (Cochenour *et al*., 2008) technique in optical wireless communication is intensity modulation; direct detection on off keying. The OPTISYSTEM software is used for simulating with the parameters shown in Table 1.

The eye diagram technique is a simple but powerful measurement method for accessing the data handling ability of a digital transmission system. This method has been used extensively for evaluating the performance of free space. The eye pattern measurements are made in the time domain and allow the effects of wave form distortion to be shown immediately on the display screen of standard BER test equipment. To sample the received waveform is when the height of the eye openings largest. This height is reduced as a result of amplitude distortion in the data signal. The vertical distance between the top of the eye opening and the maximum signal level gives the degree of distortion. The more the eye closes, the more difficult it is to distinguish between one's and zero's in the signal.

Table 1: Parameter used in numerical calculation and simulation

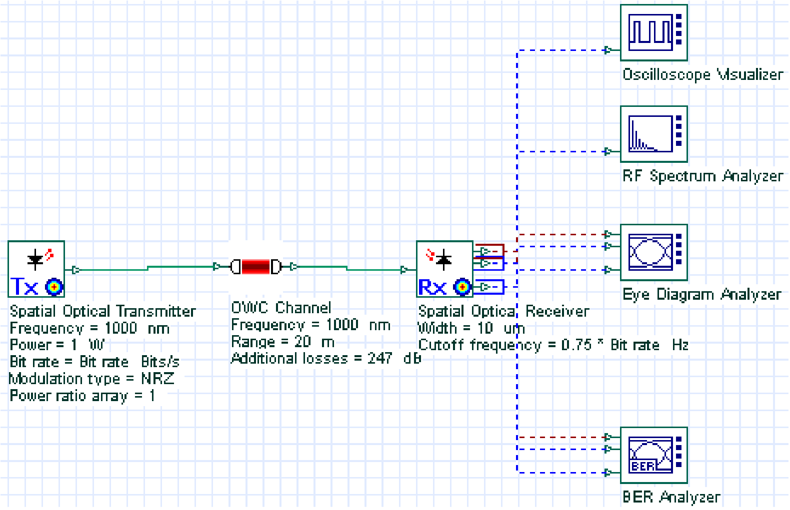
Parameter	Typical value
Extinction coefficient, clear ocean (m^{-1})	0.1514
Refractive index	1.4000
Critical angle (deg)	48-49
Transmission wavelength (nm)	1000
Optical efficiency of retro-reflector	0.9000
Optical efficiency of transmitter	0.9000
Optical efficiency of receiver	0.9000
Average transmitter power (W)	1
Data rate (Mbps), modulation type	0.5000, NRZ
Receiver aperture area (m^2)	0.0100
Retro-reflector aperture area (m^2)	0.0100
Retro-reflector beam divergence (deg)	10
Laser beam divergence angle θ_o (deg)	70
Transmitter inclination angle θ_{min}, θ_{max} (deg)	0.6800
Dark counting rate (MHz)	1
Cut-off frequency	0.7500
Counting efficiency (%)	16
Transmitter depth l (m)	20
Receiver depth x (m)	20

The height of the eye opening at the specified sampling time shows the noise margin or immunity to noise. Noise margin (Jaffe, 1995) is the percentage ratio of the peak signal voltage V_1 for an alternating bit sequence (defined by the height of the eye opening) to the maximum signal voltage V_2 as measured from the threshold level:

$$\text{The noise margin} = (V_1/V_2) \times 100\%$$

For bit error rate calculation the following link taken for clean, coastal and turbid harbour water ocean water with the underwater parameter displayed in tables.

Figure 3 shows the basic link diagram of three modes. Figure 4 and 5 shows the Link diagram for clean ocean water in retroreflector and reflective communication. Figure 6 and 7 shows the eye pattern of LOS and retro-reflector link for clean ocean water when the encoding scheme of two links is NRZ. Figure 4 and 5 shows the total photon count at 0.5 ns period for laser



Spatial Optical Transmitter
Frequency = 1000 nm
Power = 1 W
Bit rate = Bit rate Bits/s
Modulation type = NRZ
Power ratio array = 1

OWC Channel
Frequency = 1000 nm
Range = 20 m
Additional losses = 247 dB

Spatial Optical Receiver
Width = 10 um
Cutoff frequency = 0.75 * Bit rate Hz

Fig. 3: Basic link diagram

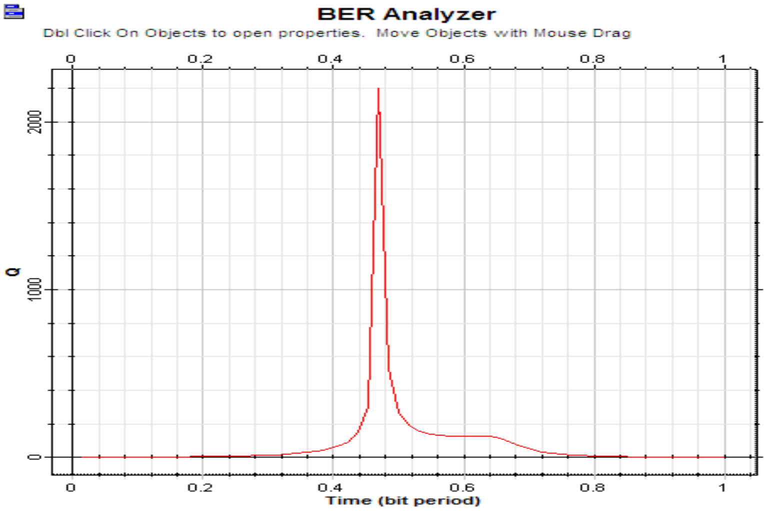


Fig. 4: Number of received photons at various timings for clean ocean water in LOS link

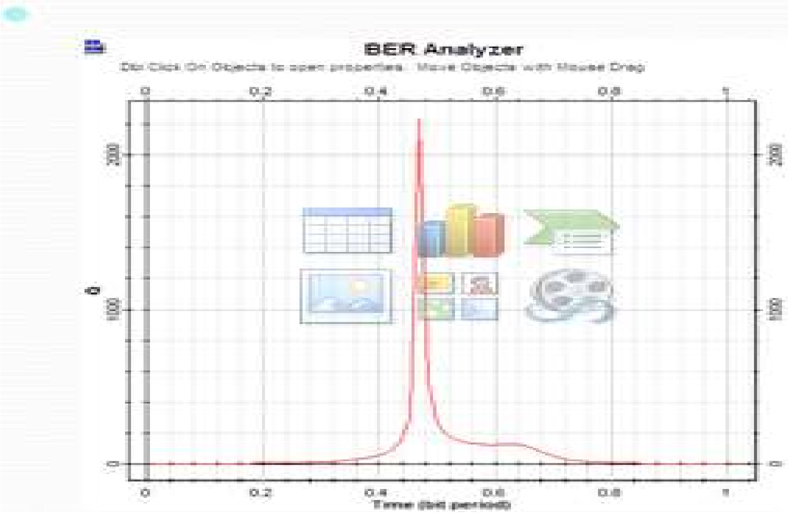


Fig. 5: Number of received photons at various timings for clean ocean water in retro-reflector link

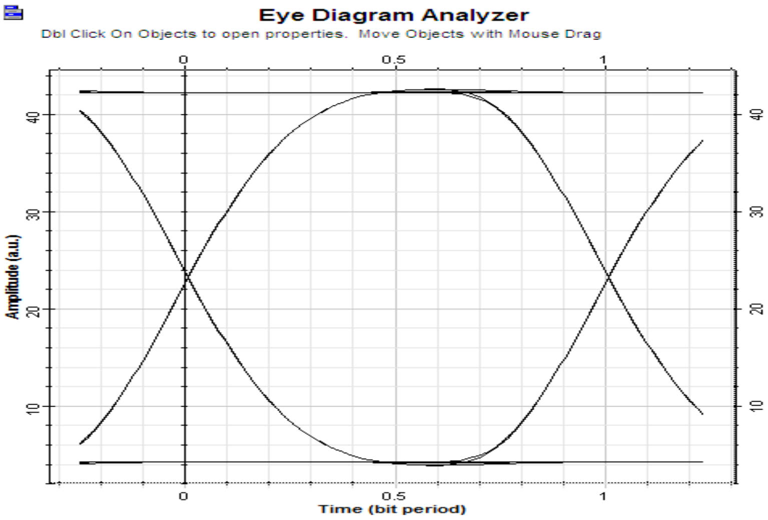


Fig. 6: Eye diagram for LOS link

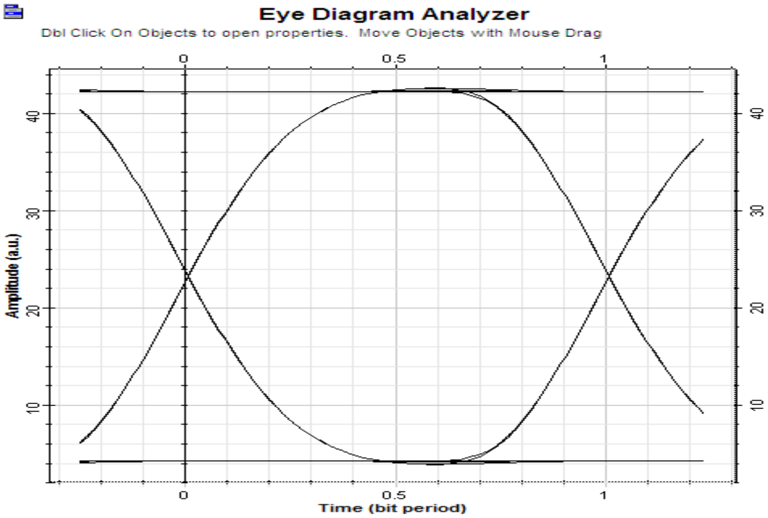


Fig. 7: Eye diagram for retro-reflector link

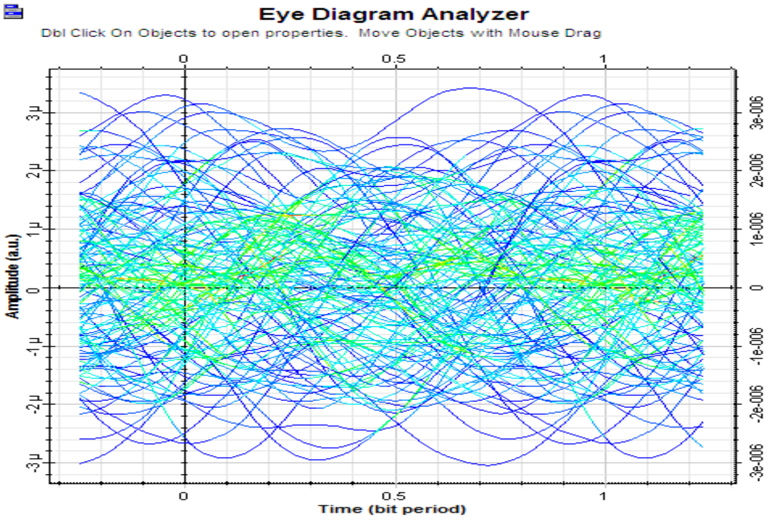


Fig. 8: Eye diagram for reflective link

source it does not show much variation but in reflective link the total photon count is very low. The number of ones and zeros error in the two schemes is almost being same when compared with the third link. Figure 8 shows the eye diagram of reflective link, the eye is closed because of noise. The maximum amplitude level is 3 μv only. When water depth increases the attenuation and the scattering parameter value is also increased.

CONCLUSION

From the above analysis we conclude the LOS link gives less bit error rate when compared with other links. If transmitter and receiver are not in LOS the retro-reflector link and reflective link is preferable. The results presented indicate that network based on underwater optical wireless links feasible at high data rates for medium distance up to hundred meters. Such networks could serve subsea wireless mobile users. In addition by placing multiple relay nodes between the chief network nodes, messages could traverse very long distances despite severe medium included limitation on the transmission range of individual links. Additional improvements to the availability of the network could be achieved by a hybrid communication system that would include an optical transceiver and an acoustical transceiver. A hybrid communication system can provide high data rate transmission by using the optical transceiver. When the water turbidity is the high or the distance between the terminals is large the system can switch to a low data rate using a acoustic transceiver, thereby increasing the average data rate and availability. However, the complexity and cost of the system are increased. In this kind of system, smart buffering and prioritization could help to mitigate short term data rate reduction.

REFERENCES

Arnon, S. and D. Kedar, 2009. Non-line-of-sight underwater optical wireless communication network. J. Opt. Soc. Am. A., 263: 530-539.

Cochenour, B.M., L.J. Mullen and A.E. Laux, 2008. Characterization of the beam-spread function for underwater wireless optical communications links. IEEE J. Oceanic Eng., 33(4): 513-521.

Duntley, S., 1971. Underwater Lighting by Submerged Lasers and Incandescent Sources. Ch. 7, Scripps Institution of Oceanography Visibility Laboratory, San Diego, CA.

Jaffe, J., 1995. Monte Carlo modeling of underwater-image formation: Validity of the linear and small-angle approximations. Appl. Opt., 34(24): 5413-5421.

Jaruwatanadilok, S., 2008. Underwater ireless optical communication channel modeling and performance evaluation using vector radiative transfer theory. IEEE J. Sel. Area. Comm., 269: 1620-1627.

Shlomi, A., 2010. Underwater optical wireless communication network. Opt. Eng., 49(1).

Zege, E.P., A.P. Ivanov and I.L. Katsev, 1991. Image Transfer through a Scattering Medium. Springer-Verlag, Heidelberg, Germany.