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A study on underwater optical wireless communication link capability in the Bay of Bengal

V. Sathyaram*[1], Shanthi Prince[2] and N. Vedachalam[3]

[1]SRM University Kattankulathur, Chennai 603203, India
[2]Department of Electronics and Communication Engineering, SRM University, Kattankulathur, Chennai 603203, India
[3]National Institute of Ocean Technology, Ministry of Earth Sciences, Chennai 600100, India

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Abstract. The paper presents a numerical underwater channel model developed in MATLAB for estimating the optical link budget between a light emitting diode (LED) based optical transmitter and a photo diode (PD) receiver when operated in the harbor, coastal and deep waters locations in the Bay of Bengal. The water samples are collected at different locations in the Bay of Bengal using a water sampler during an offshore research cruise. The optical attenuation, the main inherent parameter determining the range of the optical communication link is identified for the different waters using an underwater irradiance measurement system in the laboratory. The identified parameters are applied to the numerical model and found that a 10 W LED and a photo diode based system can provide the optical budget required for a horizontal underwater communication range of about 0.5, 14 and 35 m in the harbor, coastal and deep waters locations respectively. By increasing the transmitter power to 50 W, the operating range of the communication link could be increased up to 53 m in deep water locations in the Bay of Bengal.

Keywords: optical; underwater; wireless communication

1. Introduction

Underwater optical wireless communication (OWC) is an efficient method for achieving high data rate transmission over relatively short distances, compared to acoustic communication which are limited by bandwidth and the radio frequency signals which experience severe attenuation in the saline sea water medium (Johnson *et al*. 2014, Kaushal and Kaddoum 2016). The underwater OWC system dispenses complex wet mate connectors which require expensive work class remotely operated vehicles and the lifetime limited by the usage (Vedachalam *et al*. 2013). Considering the advantage of the non-contact data transfer capability, OWC is gaining importance in the offshore exploration and in oceanographic research applications. Few applications shown in Fig. 1 include collection of the scientific data from the subsea observatories using systems extended from the mother ship and by the hovering autonomous under water vehicles. The recently commercialized underwater OWC systems based on the LED and LASER transmitters claim to operate with data transfer rates of 12.5 Mbps and 0.5Gbps with a range of 150 m and 10 m

*Corresponding author, Scientist, E-mail: veda1973@gmail.com

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respectively, is dependent on the optical properties of the ocean waters in which they are operated (Baiden *et al*. 2009, Sonardyne 2016, Farr *et al*. 2010). In contrary to the LASER based systems used for point to point communication, LED transmitters are more suitable for fly-by data exchange between the seabed located sensors and the dynamic vehicle (Zhang and Dong 2015).

The second section describes the sea water parameters determining the optical attenuation, the third section presents the ocean water collection and identification of the optical attenuation parameters, and the last section presents the mathematical model and the simulation results describing the effective operating range of the OWC system when operated in turbid harbor, coastal and in the deep water locations in the Bay of Bengal.

2. Underwater channel optical properties

An underwater OWC system design requires precise characterization of the optical attenuation of the specific underwater channel in which the system is to be operated (Johnson 2013). The parameter is essential for determining the optical link budget, the optical transmitter power and the detection sensitivity of the optical receiver. The physical properties of the ocean water vary with the water depth and the geographical location (Fan *et al.* 2015). The optical property of the water is mainly dependent on the absorption and scattering of the light due to the chlorophyll content in sea water. The euphotic zone receives maximum sunlight supporting photosynthesis. Beneath lies the dysphotic zone which receives reduced sunlight. In the aphotic zone, which is still below, sunlight never reaches. Hence every zone has its own inherent optical properties which pose challenge when determining the required power link budget for the desired range of communication (Kazemiam and Kashani 2013).

The attenuation of the optical signals in the sea water channel due to the process of absorption and scattering is described in Eq. (1) as

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

The spectral absorption coefficient a(λ) described in Eq. (2) is

$$a(\lambda) = a_w(\lambda) + a_{cl}(\lambda) + a_h(\lambda) + a_f(\lambda) \tag{2}$$

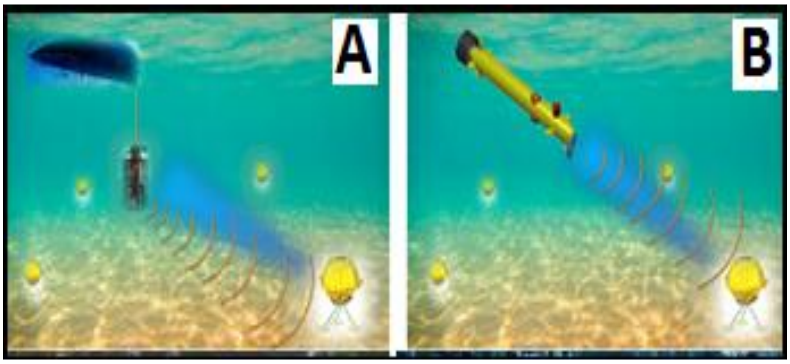

Fig. 1 Rendering showing OWC in data collection from an offshore node

Table 1 Attenuation for water types (Kaushal and Kaddoum 2016, Farr *et al*. 2010)

Type	C(λ) in m^{-1}
Clear ocean	0.151
Coastal ocean	0.298
Turbid harbor	2.170

which includes the wavelength specific absorption coefficients of the pure water, chlorophyll, fulvic and humic acids present in the sea water. In the visible spectrum region, the sea water absorption coefficient is the minimum for 470 nm wavelength, which is the blue-green region (Johnson *et al*. 2014, Kaushal and Kaddoum 2016, Jaruwatanadilok 2008).

The scattering is mainly caused by the particles of size comparable to the wavelength of the incident light. Scattering in the coastal water is due to the combined effect of both the organic and inorganic particles suspended in the water medium, whereas organic particles are the main cause for scattering in the deep sea environment. The water salinity and the temperature also has the effect on the scattering (Kumar *et al*. 2017, RAMSES 2017). The scattering coefficient of light in sea water described in Eq. (3) is

$$b(\lambda) = b_w(\lambda) + b_s^{\circ}(\lambda)C_s + b_l^{\circ}(\lambda)C_l \tag{3}$$

which includes the scattering coefficients contributed by small and larger particles compared to the wavelength of the light. The Rayleigh scattering occurs if the particulate size is smaller than the wavelength and the Mie scattering when the particle sizes are larger than the wavelength (Sonardyne 2016). In an optical communication system, the spectral volume scattering function (VSF) is the fraction of the incident power scattered out of the beam through an angle ϕ into a solid angle ΔΩ centered on β is obtained by integrating the VSF over all directions is described by the Eq. (4)

$$b(\lambda) = 2\pi \int_0^{\pi} \beta(\Psi, \lambda)\sin(\Psi)d\Psi \tag{4}$$

The scattering process attenuates the optical signal reducing the Signal to Noise Ratio (SNR), which is an essential parameter determining the quality of the underwater communication (Baiden *et al.* 2009).

Based on Jerlov's and subsequent classifications (Johnson *et al.* 2014, Kaushal and Kaddoum 2016), the optical attenuation coefficient for different ocean waters and the suitable operational wavelengths are shown in Table 1.

3. Water sampling and identification of attenuation coefficients

The water sample collection is carried out using the underwater in situ sampler system type SBE 37 (Fig. 2) installed onboard the NIOT research vessel Sagar Nidhi during the cruise number SN 123 on 8 Oct 2017. The geo-coordinates of the location, water depth of the location classification is indicated in Table 2

Determination of the optical attenuation is done using the experimental setup shown in Fig. 3. The underwater hyperspectral irradiance sensor TriOS Ramses ACC-VIS capable of measuring the visible light in the region 320-950 nm is used for the measurement of irradiance at various separation distances from the LED transmitter. The instrument based on n-channel silicon PD array is capable of measuring spectral intensities up to 8 $W/m^2/nm^{-1}$ in the 500 nm region with 0.3 nm spectral accuracy and has a noise equivalent irradiance of 0.4 $\mu W/m^2/nm^{-1.}$ (OSI Optoelectronics 2006)

Table 2 Details of the water sampled locations

Location	Water depth	Classification
13° 06.76' N, 80° 18.63' E	10 m	Coastal
13° 05.99' N, 80° 17.79' E	2 m	Harbor
12° 59.54' N, 80° 37.47' E	195 m	Deep sea

Fig. 2 Water sampler used for sample collection up to 195 m water depth

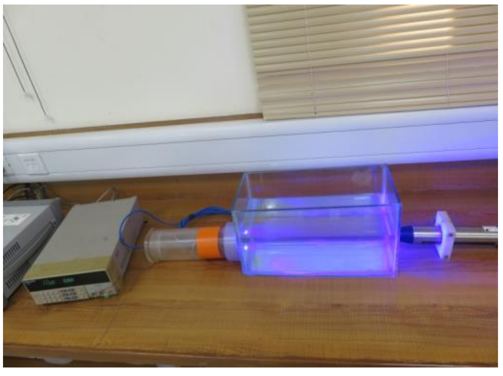

Fig. 3 Experimental setup for determination of attenuation coefficients

Table 3 Measurement data and computed attenuation

Water type	Irradiance in receiver mW/sq.mm	Electrical power at receiver mW	Computed attenuation coefficient
Deep sea (195 m)	350	274	0.11
Coastal	316	248	0.24
Turbid	47	37	2.62

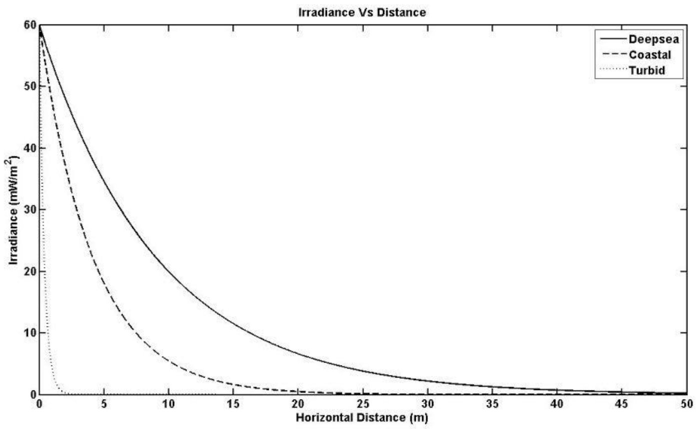

Fig. 4 Link distances in various ocean waters for 300 mW transmitter power

The optical transmitter comprises of a 10 W blue LED with a 45° convergent lens. The glass tank 0.8 m long, 0.4 m high and 0.5 m width is filled with the sea water samples. During the tests the LED is provided with a constant power input of 300 mW and the distance between the transmitter and the irradiance sensor is maintained as 0.8 m. The Beer-Lambert exponential relationship (Kaushal and Kaddoum 2016) shown in the Eq. (5) and is used for determining the attenuation (λ), with a constant path length Lm of 0.8 m and P_T of 300 mW and the results are shown in Table 3.

4. Simulation results

The mathematical model is developed in MATLAB based on Beer-Lambert relationship shown in Eq. (5) and the attenuation coefficients identified by the experiments for the deep sea, coastal and turbid waters. The simulation results showing the optical irradiance with increasing distances for a transmitter power of 10W for the three water categories is depicted in Fig. 4. It can be seen that the optical irradiance is about 1 mW/m^2 at 0.5, 14 and 35 m for the harbor, coastal and deep water respectively in the Bay of Bengal, which is the irradiance level required for detection by a typical photo diode based receiver (OSI Optoelectronics, 2006).

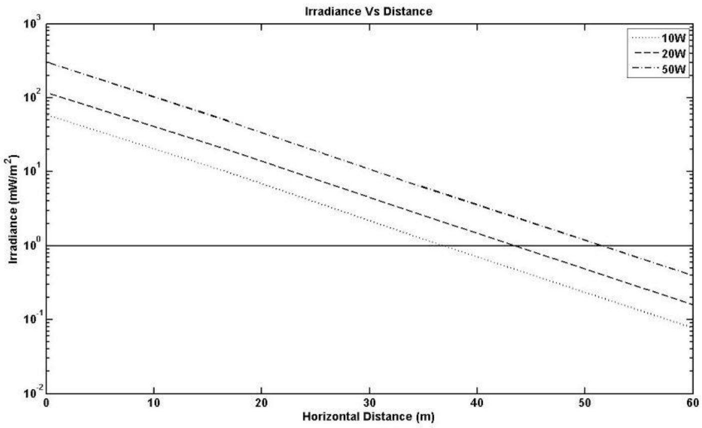

Fig. 5 Horizontal link distances for higher transmitter power

Simulations are done for higher transmitter power of 20 and 50 W and the results are shown in Fig. 5. The y-axis is represented in the logarithmic scale in order to indicate the irradiance level at longer distances clearly. It can be seen that by increasing the transmitter power to 50 W, the operating range the communication link with a PD receiver capable of detecting 1 mW/m^2 could be effective up to 53 m in deep water locations in the Bay of Bengal. However, the final OWC system design should take into consideration the transmitter power, receiver sensitivity, modulation method, aiming and the tracking strategies, ambient light level and the electronics system noise. While the PD is limited by the detection threshold of 1 mW/m^2, the Avalanche Photo Diodes and the recently developed silicon photo multiplier systems could detect intensities up to a few pico Watts. Thus the receiver sensitivity plays a deciding role in the final capability of the OWC system. In addition, the beam divergence and the maximum misalignment between the transmitter and the receiver operating in the hydrodynamic environment also plays a significant role in the data transmission capability of the system.

5. Conclusions

Based on the water samples collected in the Bay of Bengal and the optical attenuation coefficients identified in the laboratory, a numerical model is developed and simulations are done to identify the maximum range of a LED-PD based wireless optical communication system when operated in the Bay of Bengal. It is identified that the underwater horizontal communication range shall be about 0.5, 14 and 35 m in the harbor, coastal and deep waters locations respectively. By increasing the transmitter power to 50 W, the operating range of the communication link could be increased up to 53 m in deep water locations in the Bay of Bengal.

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References

Baiden, G., Bissiri, Y. and Masoti, A. (2009), "Paving the way for a future underwater omni directional wireless optical communication systems", *Ocean Eng*., **36**(9-10), 633-640.

Fan, Y., Li, W., Calzado, V. S., Trees, C., Stamnes, S., Fournier, G. and Stamnes, K. (2015), "Inferring inherent optical properties and water constituent profiles from apparent optical properties", *Opt. Express*, **23**(15), 987-1009.

Farr, N., Ware, J., Pontbriand, C., Hammar, T. and Tivey, M. (2010), "Optical communication system expands CORK seafloor observatory's bandwidth", IEEE Oceans-Seattle, USA.

Jaruwatanadilok, S. (2008), "Underwater wireless optical communication channel modeling and performance evaluation using vector radiative transfer theory", *IEEE J. Selected Areas Commun*., **26**(9).

Johnson, L.J., Green, R.J. and Leeson, M.S. (2013), "Underwater optical wireless communications: depth dependent variations in attenuation", *Appl. Optics*, **52**(33), 7867- 7873.

Johnson, L.J., Jasman, F., Green, R.J. and Leeson, M.S. (2014), "Recent advances in underwater optical wireless communications", *Underwater Technol*., **32**(3), 167-175.

Kaushal, H. and Kaddoum, G. (2016), "Underwater optical wireless communication", *IEEE Access*, **4**, 1518-1547.

Kazemiam, E. and Kashani, F.D. (2013), "Reliability analysis of underwater optical communication link in different locations through Caspian sea", *Optik*, **124**, 5184-5188.

Kumar A., Prince S., Vedachalam, N and Doss Prakash, V. (2017), "Ocean water channel modelling and estimation of power link budget for underwater wireless link. In: Wireless communication Signal Processing and networking", International conference on. Chennai: IEEE.

OSI Optoelectronics (2006), Photodiode characteristics and applications. Retrieved from: http://www.osioptoelectronics.com/application-notes/an-photodiode-parameters-characteristics.pdf

RAMSES, (2017), Hyperspectral Radiance and Irradiance Sensors for the UV, VIS or UV/VIS range, http://www.trios.de/en/products/sensors/ramses.html.

Sonardyne. (2016), "Sonardyne underwater wireless optical communication system", Retrieved from :www.sonardyne.com/wp-content /uploads/2016/06/BlueComm.pdf

Vedachalam, N., Ramesh, R., Muthukumaran, D., Aarthi, A., Subramanian, A., Ramadass, G.A. and Atmanand, M.A. (2013), "Reliability-centered development of deep water ROV ROSUB 6000", *J. Marine Technol*., **47**(3), 55-71

Zhang, H. and Dong, Y. (2015), "Link misalignment for underwater wireless optical communications", In: Advances in Wireless and Optical Communications (RTUWO), Riga: IEEE, 215-218.

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