BER Performance of Spectral / Spatial OCDMA for UWO Link Using Perfect Difference Code

Md. Rabiul Islam[1], Anik Kumar Das[2], Md. Safayat Hossain Sowrov[3], Omar Faruk Hemal[4]

Department of Electrical and Electronic Engineering
Bangladesh Army University of Science and Technology
Saidpur Cantobment, Nilphamari
Email: rabiulislam[at]baust.edu.bd[1], anik.eee.baust07[at]gmail.com[2], safayatsowrov29[at]gmail.com[3], eee.180102021[at]gmail.com[4]

Abstract: ***In this paper, the performance of spectral/spatial optical code division multiple access (2D-OCDMA) system through underwater wireless optical (UWO) medium is evaluated where 2D perfect difference codes are used as user code address. In the proposed system, a LED of 532nm wavelength is considered as optical source whereas p-i-n photodiode is employed as optical detector. PIIN, thermal noises and shot noises are taken into consideration while calculating the bit error rate (BER) of the system. The performance of the proposed system is analyzed for various types water medium (i.e., pure sea water, clear ocean water and coastal ocean water). The BER performance is ascertained as a function of transmitter power, link distance, data rate and received power through water medium. It is found that the system BER performance significantly depends on the water types. The best system performance is obtained in pure sea water due to the least amount of impurity where clear ocean water provided better results than coastal ocean water having the highest amount of impurity. From numerical results it is observed that best BER performance can be achieved for lower distance of transmission in pure sea water channel among all water channels. The system BER performance degraded with increasing the link distance while increased transmitted optical power improves the system performance.***

Keywords: BER performance, 2D-OCDMA, UWO communication, water types, perfect difference code

1. Introduction

In recent years, underwater wireless optical communication (UWOC) has been playing an important role for different applications such as ocean currents monitoring, weather forecasting, seismic monitoring, control surveillance systems, real-time monitoring, environmental research, climate condition recording, oceanography research, forecasting, transmission of data between ships etc. [1]-[6]. Currently, acoustic technology is the most widely used underwater wireless communication technique but it suffers from both low bandwidth and high latency [9]. Electromagnetic (EM) waves, in the radio frequency (RF) range, are a good option for underwater wireless communication when used for high data rate transfer in short distances. However, due to strong water attenuation, radio frequency-based communication technologies are rarely used for underwater wireless communication [1]-[5]. Optical wave provides less attenuation, higher data rate, higher bandwidth, smaller propagation delay, lower latency, less power losses and more energy efficiency [7].

However the implementation of UWOC is not easy and it faces some hindrance that is difficult to overcome. The main drawbacks of UWOC is the restricted link distance. The maximum attainable communication link distance is below 100 m only [8]-[9]. Optical signal while travelling through water medium faces many hindrances such as absorption, scattering and atmospheric turbulence which causes the change in direction of the optical beam, intensity loss of received optical power, spreading of optical beam, multipath interference etc. These effects are actually unavoidable in UWOC and greatly degrade communication quality [4]

Among many optical access technology, Optical Code Division Multiple Access (OCDMA) is experiencing much attention because of its many attractive features such as efficient bandwidth utilization, better security, improved spectral efficiency, and increased robustness [2], [6]. Since OCDMA allows many users to access the network at the same time with same frequency, it produces multi user interference (MUI). MUI is the primary performance degradation factor in OCDMA systems. Among many OCDMA techniques, two dimensional-OCDMA (2D-OCDMA) system with interference cancellation receiver is a popular technique to reduce the effect of multiuser interference (MUI). However, to mitigate the MUI, 2D-OCDMA system must be implemented with code sequence that possesses the property of fixed in-phase cross-correlation value [4]. The application of 2D Perfect Difference (2D-PD) codes will be beneficial as it has unity in- phase cross-correlation value [4]. It is also noted that 2D-PD codes with spatial/spectral transceiver structure can more effectively suppress the phase induced intensity noise (PIIN) and reduce the effect of MUI in OCDMA.

2. System Description

The schematic block diagram of the underwater wireless 2D-OCDMA is shown in Fig. 1. A set of a combiner and a splitter is used to combine the signals from all transmitters and broadcast them to all receivers. Here, the user code sequence is addressed using 2D-perfect difference codes. Let us consider there are K number of users in the system. At the transmitter, the user binary data is modulated by an on-off keying (OOK) modulator using a broadband optical source. Then the modulated signal is fed to the combiner via a 2D-OCDMA encoder. The structure of the encoder can be fabricated by the Fiber Bragg Gratings (FBGs) array structure [3].

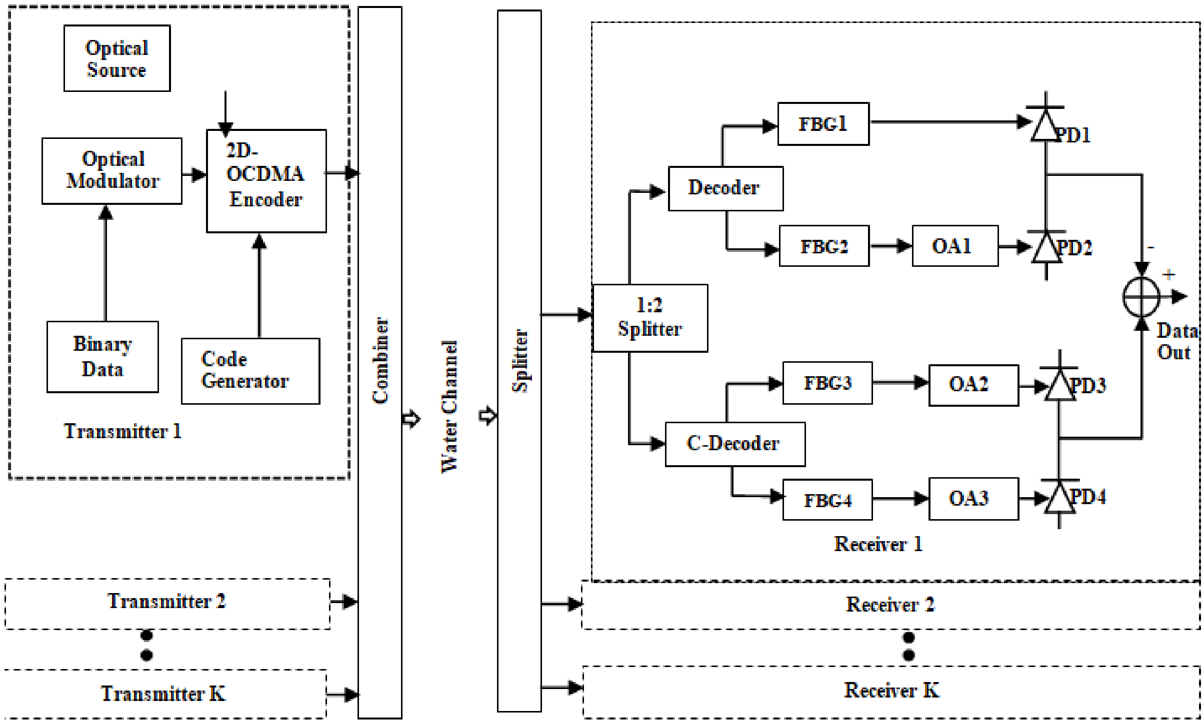

Figure 1: Block diagram of the proposed 2D-OCDMA UWOC system

3. System Analysis

3.1 Underwater Link Design

In designing the UWOC system, the prior consideration is to comprehend the link budget equation. For the line of sight (LOS) link, the link budget equation is given by [1] and [2],

$$P_R = P_T\eta_T\eta_R \frac{A_R\cos(\varphi)}{2\pi d^2[1-\cos(\varphi_0)]}\exp\left[-c(\lambda)\frac{d}{\cos(\varphi)}\right] \quad (3.1)$$

Where P_T is the transmitted optical power, P_R is the received optical power by the receiver after a distance of d, φ is the transmitter inclination angle from the axis connecting the transmitter-receiver pair, A_R is the receiver aperture area, η_T and η_R are the optical efficiencies of the transmitter and the receiver, respectively, d is the transmission distance, φ_0 is the transmission beam divergence angle. The total loss coefficient for an underwater optical channel $c(\lambda)$ is defined as [2-3], [4],

$$c(\lambda) = a(\lambda) + b(\lambda) \quad (3.2)$$

The attenuation coefficient is denoted as $c(\lambda)$ m^{-1}, where λ is the source wavelength. If where $a(\lambda)$ and $b(\lambda)$ are the underwater optical absorption and scattering coefficient, respectively. $a(\lambda)$ depends on the dissolved impurities in water, chlorophyll concentration, transmission wavelength, and link distance; $b(\lambda)$ is dependent on chlorophyll concentration, wavelength, small and large water-soluble particles in water [6-9].

3.2 The Bit Error Rate Calculation

PIIN, thermal noise, and short noise are considered for the calculation of the BER of the system. The signal to noise ratio (SNR) can be calculated as:

$$SNR = \frac{I_r^2}{I_t^2} \quad (3.3)$$

Where I_t is the total noise power affecting all the photodiodes and I_r is total photocurrent of receiver. The photocurrent I_r can be expressed as:

$$I_r = \frac{RP_{rec}w_1}{M} \quad (3.4)$$

where P_{rec} is received optical power, w_1 is code weight of spectral code sequence, M is the code length of spectral code sequence, and R is the of photodetector responsivity.

If the variance due to PIIN, shot noise and thermal noise are I_{PIIN}^2, I_{Shot}^2 and $I_{Thermal}^2$, respectively, then I_t^2 can be illustrated as [2],

$$I_t^2 = I_{PIIN}^2 + I_{Shot}^2 + I_{Thermal}^2 \quad (3.5)$$

In the case of 2D-perfect difference code, the PIIN can be expressed as:

$$I_{PIIN}^2 = \frac{R^2 B_e P_{rec}^2}{2M\Delta f w_2^2 w_1 (MN-1)^2} \left\{ \left(w_1 w_2 (MN-1) + w_2 (U-1)(M-1)\right)^2 + \frac{w_2^2 (U-1)^2 (M-1)^2}{(w_1-1)^2} \right\} \quad (3.6)$$

Where B_e is receiver electrical bandwidth, Δf is source bandwidth, w_2 is code weight of spatial code sequence and N is the code length of spatial code sequence.

As the thermal noise is highly dependent on receiver noise temperature, it can be represented as:

$$I_{Thermal}^2 = \frac{4K_b T_m B_e}{R_{Load}} \quad (3.7)$$

Where K_b is Boltzmann constant, R_{Load} is receiver load resistance and T_m is the noise temperature of receiver.

The shot noise can be written as:

$$I_{Shot}^2 = \frac{eB_e P_{rec} R}{w_2 M} \left\{ w_1 w_2 + \frac{2w_1 (U-1)(N-1)}{(MN-1)} + \frac{2w_2 (U-1)(M-1)}{(MN-1)} + \frac{4(U-1)(M-1)(N-1)}{(MN-1)} \right\} \quad (3.8)$$

The SNR at the receiver can be expressed as:

$$SNR = \frac{I_r^2}{I_{PIIN}^2 + I_{Shot}^2 + I_{Thermal}^2} \quad (3.9)$$

The BER of the system can be expressed as:

$$BER = \frac{1}{2} erfc\left(\sqrt{SNR/8}\right) \quad (3.10)$$

4. Results and Discussion

In this section, the BER performance of UWOCDMA system for various water types has been presented. The system parameters are following: the transmission wavelength (λ) = 532nm, data rate (D_r) =0.5GHz , the transmitter optical efficiency (η_t) = 0.9, receiver optical efficiency (η_r) = 0.9, LED beam divergence angle (θ_0) = 40^o, transmitter inclination angle (θ) =15^o, receiver capture area (A_r) = 0.01m^2, electron charge $(e) = 1.6\times10^{-19} C$, Boltzmann constant (k_b) = 1.38×10^{-23}J/K and temperature (T) = 298K, Photo detector responsivity (R) =0.85, receiver load resistance R_{load} = 100Ω, electrical bandwidth (B_e)= 250MHz, total number of simultaneous user (U) =50, transmitter power (P_t) =30dBm are considered. The code weight of spectral and spatial code sequence is 6 and 3 respectively.

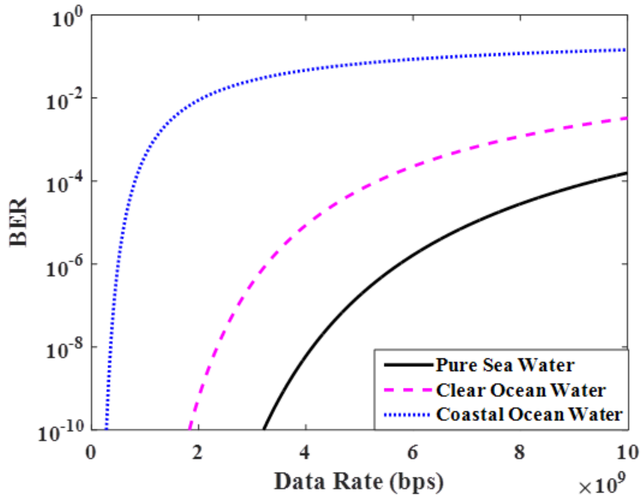

Figure 2: BER versus distance of transmission curve when total simultaneous user is 50 and transmitted power is 30 dBm

Figure 2 expresses the BER versus data rate for various types of water. Here the transmission beam divergence angle is 50°, inclination angle is 10°, the link distance of transmission is 10m, the number of simultaneous users is 20 and transmitter power is 30dBm. The value of spectral and spatial code sequence is 3 and 2 respectively. As the data rate increases the BER also increases significantly. So it can be stated that the system performance greatly depend on data rate. The BER of 10^{-8} is gained at 4.2×10^9 bps, 2.46×10^9 bps and 3.6×10^8 bps in pure sea water, clear ocean and coastal ocean water respectively. In pure sea water the system's data rate is greater with maintaining a BER of 10^{-8}. The BER performance is reduced in clear ocean water and coastal ocean water channel as the absorption and scattering of the optical signal increases with high level of impurities.

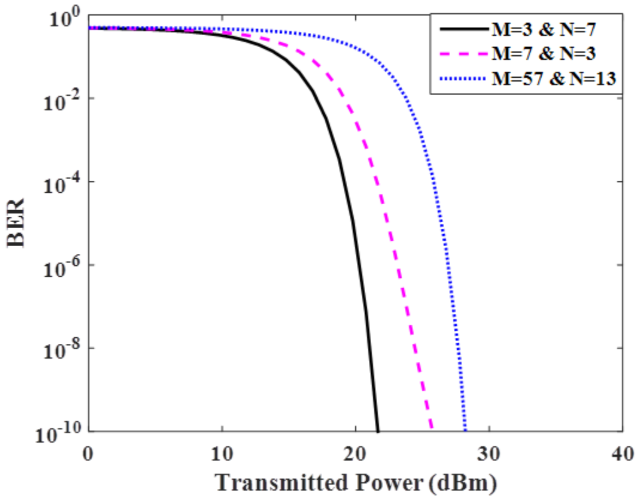

Figure 3: BER versus transmitted power curve with the variation of code length when number of simultaneous user is 50, link distance is 10m and inclination angle is 15°

Figure 3 illustrates the BER versus transmitted power curve with the variation of code length of spectral code sequence and spatial code sequence. Here the link distance of 10 m. Here the transmission beam divergence angle is 40°, inclination angle is 15° and the number of simultaneous users is 50. When the value of spectral and spatial code sequence is 2 and 3 then we get the value of spectral code length and spatial code length is 3 and 7 respectively. It is seen that the required transmitted power is 20.5 dBm when the value of spectral code length and spatial code length is 3 and 7. Then we see that when the value of spectral and spatial code sequence is 3 and 2 then we get the value of spectral code length and spatial code length is 7 and 3 respectively. In that case the system BER of 10^{-8} is achieved at 24 dBm. When the value of spectral and spatial code sequence is 8 and 4 then we get the value of spectral code length and spatial code length is 57 and 13 respectively. Here the system BER of 10^{-8} is achieved at 27 dBm. The performance is analyzed for pure seawater. It is clear that the required transmitted power is increased with increasing the value of spectral and spatial code length.

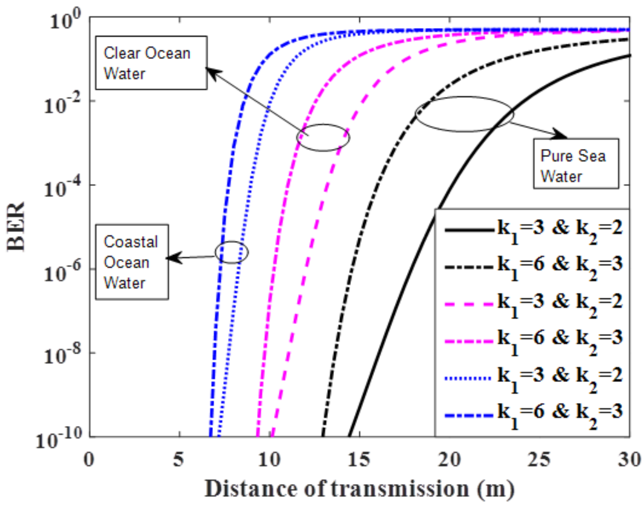

Figure 4: BER versus distance of transmission curve with the variation of code weight when number of simultaneous user is 50 and inclination angle is 10°.

Figure 4 expresses the BER versus transmission link distance for various types of water with the variation of spectral code weight and spatial code weight. Here the transmission beam divergence angle is 40°, inclination angle is 10°, the number of simultaneous users is 50 and transmitter power is 30dBm. The value of spectral and spatial code sequence is 3 and 2, then the BER of 10^{-8} is gained at 16.5m, 11.5m and 8m in pure sea water, clear ocean and coastal ocean water respectively. When the value of spectral and spatial code sequence is 6 and 3, then the BER of 10^{-8} is gained at 14m, 9.5m and 7m in pure sea water, clear ocean and coastal ocean water respectively. As the distance between the links increases the BER also increases significantly. Also when the code weight of spectral and spatial code sequence is increased the BER is also increases. That means the system performance reduced. It is also found that when the value of code weight is increased the distance of transmission is reduced. So it can be stated that the system performance greatly relies on link distance. In pure sea water the system can cover a much larger distance maintaining a BER of 10^{-8}. The BER performance is worst in coastal ocean water channel as the absorption and scattering of the optical signal increases with high level of impurities.

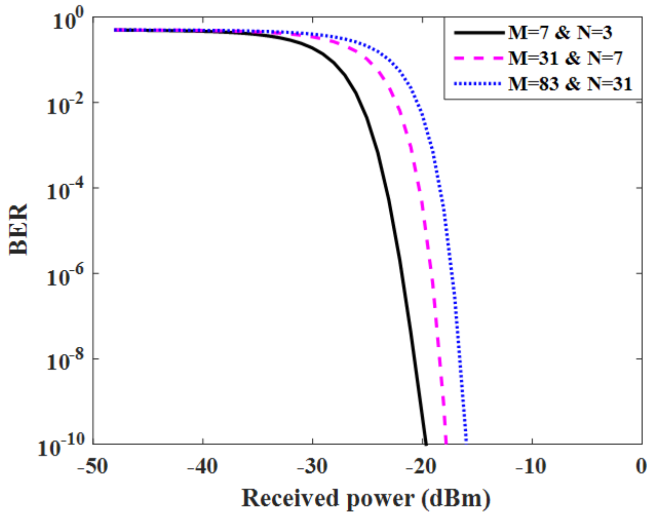

Figure 5: BER versus receiver power curve when number of simultaneous user is 45, transmission beam divergence angle is 60° and inclination angle is 10°

Figure 5 illustrates the BER versus received power curve with considering the link distance of 10 m. Here the transmission beam divergence angle is 60°, inclination angle is 10°, and the number of simultaneous users is 45. When the value of spectral code length and spatial code length 7 and 3 then the system BER of 10^{-8} is obtained at -21 dBm received power. But when we increase the code length of spectral and spatial code sequence then the receiver power is increased. The system BER of 10^{-8} is obtained at -18 dBm receiver power while considering the spectral code length and spatial code length is 31 and 7 respectively. But the received power is increased to -16 dBm when the value of spectral and spatial code length is 83 and 31 respectively. It is seen that the received power is increased while increasing the system's code length of perfect difference code. The performance is analyzed for pure sea water.

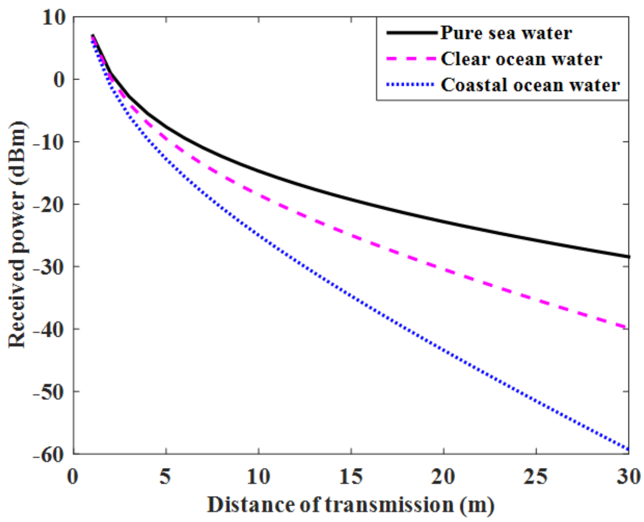

Figure 6: Received power versus distance of transmission curve when number of simultaneous user is 45, transmission beam divergence angle is 40° and inclination angle is 10°

Figure 6 shows the received power versus distance of transmission curve for various types of water such as pure seawater, clear ocean water and coastal ocean water. Here the transmission beam divergence angle is 40°, inclination angle is 10°, the number of simultaneous users is 45 and transmitter power is 30dBm. The value of spectral and spatial code sequence is 6 and 2 respectively. It is seen that when the transmission distances increases the value of received power is decreased. This is due to the absorption and scattering of the optical signal increases with high level of impurities. For transmission distance of 20m the received power is -22.81 dBm, -30.43 dBm and -43.40 dBm in pure seawater, clear ocean water and coastal ocean water respectively. So it is said that the the system performance is better in pure seawater.

5. Conclusion

In this paper, an underwater wireless spectral/spatial OCDMA system using 2D-PDCs is discussed and the impact of code weight and code length of the system is analyzed. In this analysis different types of sea water are taken into account considering PIIN, shot noise and thermal noises. BER performance regarding different system parameters such as link distance, received power, transmitter power and data rate is investigated for different sea water. It is observed that the system performance greatly dependent on code weight and code length of spectral code sequence and spatial code sequence. It is also seen that the higher code weight and code length increases the transmitted power. It can also be stated that the system performance greatly relies on link distance. In pure sea water the system can cover a much larger distance maintaining a BER of 10-8. The BER performance is worst in coastal ocean water channel as the absorption and scattering of the optical signal increases with high level of impurities.

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