Investigation of Jervol Water Types Properties Effects on Underwater Optical Wireless OCDMA System Performances for Different Modulation Techniques

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Investigation of Jervol Water types properties effects on Underwater Optical Wireless OCDMA System Performances for Different Modulation Techniques

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Abstract In this paper , an analytical evaluation of direct detection OCDMA system using zero cross correlation codes is presented in an underwater wireless optical channel (UWOC). Performances were evaluated by varying the main simulation parameters (range,transmitted power,number of users and inclination angle) considering different modulation techniques for different water types (categorized according to Jerlov classification).

Keywords UWOC · OCDMA · Optical Modulations · Attenuation · Water type

1 Introduction

Underwater wireless optical communications (UWOC) has become the focus subject of many recent wireless communications studies Kaushal and Kaddoum (2016). Allowing high data rates it represents the ideal candidate for underwater transmissions (compared to few kbits/s rates achievable by acoustic and radio-frequency (RF) underwater communicationsChen et al. (2019); Khalighiet al. (2014); Saeed et al. (2019).
In optical oceanography , Jerlov categorized waters into oceanic and coastal types based on it's chlorophyll concentration Solonenko and Mobley (2015) . The latter directly affecting the water's particles sizes and consequently the scattering and absorption effects on any light beam propagation underwater. The objective of this study is , considering these drawbacks, to translate the benefits of Optical Code Division Multiple Acces (OCDMA, more traditionally implemented in optical fibers systems) in UWOC systems.
This paper is organized as follows : In section 2, the UWOC/OCDMA studied

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system is presented, followed by the channel properties in section 3. Section 4 is devoted to the Bit error rate calculations considering different modulations schemes. The results issued from these calculations are finally presented and discussed in section 5.

2 System description

The studied system is represented in Fig. 1. On the transmission side each user's spectral signature (defined by it's respective ZCC code sequence) is the modulated the user's data (the different modulation techniques considered in this study are detailed later in this paper,see section 4). It's then diffused thru the water channel by optical lenses. The water inherent properties and particles will strongly affect the signal power. At the receiver, direct detection (DD) technique is used. Introduced by Abdullah et al. (2008) , it consists of the detection of only one of the spectral signature's wavelengths (due to the fact that there is no overlap between the ZCC codes users). It allows a simpler system (compared to optical balanced detection conventionally used) , and the low value of captured power at the receiver (do to the fact that only wavelength is detected) will allow us to test the system limitations for the most critical case (the captured power is ω times smaller than the one studied in Al Hammadi and Islam (2020) and Yadav and Kumar (2020) , ω being the code weight).

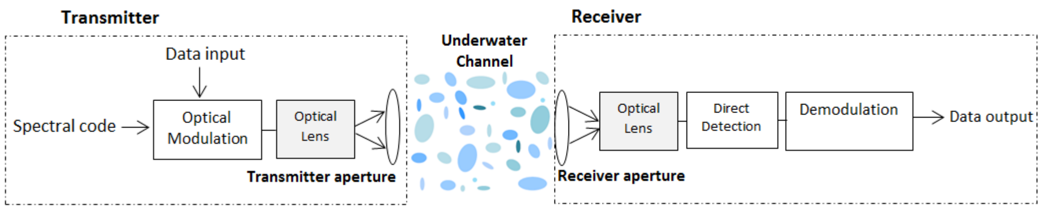

Fig. 1 Schematic diagram of OCDMA UWOC system

3 UWOC channel properties

Line of sight (LOS) , link configuration , defines the path of communication between transmitter (T_x) and receiver (R_x), as shown in Fig. 2 .In this scenario, (T_x) directs the light beam in the direction of (R_x), where the captured power (in the case of a LOS link of distance d) P_{Rx} is defined as Ghassemlooy et al. (2019):

$$P_{Rx} = P_{Tx}\eta_{Tx}\eta_{Rx}\frac{A_{Rxeff}\cos(\varphi)}{2\pi d^2\left[1-\cos\left(\varphi_0\right)\right]}\exp\left[-c(\lambda)\frac{d}{\cos(\varphi)}\right] \quad (1)$$

Table 1 Absorption , scattering and extinction coefficients for different water types (according to Jerlov classification)

Jerlov water type	$a(m^-1)$	$b(m^-1)$	$c(m^-1)$
Clear water	0.053	0.003	0.056
Clear ocean	0.069	0.08	0.15
Coastal ocean	0.088	0.216	0.305
Turbid harbor	0.295	1.875	2.17

Where: P_{Tx} is the transmitted power, η_{Tx} and η_{Rx} are respectively the optical efficiency of the transmitter and the receiver and A_{Rxeff} is the effective aperture area of the receiver.
The captured power also depends on the transmission beam divergence angle φ_0 and the transmitter inclination angle φ. Those angles are illustrated in Fig. 2 for a LOS link configuration.

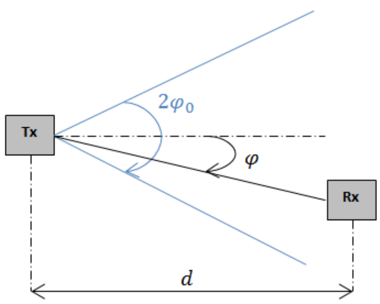

Fig. 2 Beam divergence angle (φ_0) and transmitter inclination angle (φ) in LOS link

Another important parameter to take into consideration is the attenuation coefficient $c(\lambda)$. In UWOC it depends on the operating transmission wavelength. It's also defined as sum of absorption and scattering coefficient respectively represented by $a(\lambda)$ and $b(\lambda)$ Rashed and Sharshar (2013) :

$$c(\lambda) = a(\lambda) + b(\lambda) \tag{2}$$

$a(\lambda)$ and $b(\lambda)$ depend on the concentration of suspended and dissolved particles in the water Rashed and Sharshar (2013), both of which directly affect the light beam propagation. By referring to Jerlov water classification , the typical values of absorption , scattering and extinction coefficients for different water types are listed in table 1:

4 BER calculation

The Signal to Noise Ration (SNR) is defined , depending on the average signal power i_k and average power of all noise sources σ, as :

$$SNR = \frac{{i_k}^2}{\sigma^2} \tag{3}$$

The total variance of noise sources σ^2 is defined as the sum of shot noise variance (${\sigma_{sh}}^2$) and thermal noise variance (${\sigma_{th}}^2$). In the studied case, the phase induced intensity noise (PIIN) is neglected to the ZCC codes properties (no spectral signatures overlapping between all active users). Hence , considering DD receiver, i_k and σ can be expressed as (demonstration detailed in Garadi et al. (2017)):

$$\mathrm{i_k} = \Re.\mathrm{P_{sr}}\frac{1}{\mathrm{L}} \tag{4}$$

and

$$\sigma^2 = 2.\mathrm{e.B.i_k} + \frac{4\mathrm{k_b T_n B}}{\mathrm{R_1}} = 2.e.\mathrm{B}.\Re.\mathrm{P_{sr}}\frac{1}{\mathrm{L}} + \frac{4\mathrm{k_b T_n B}}{\mathrm{R_1}} \tag{5}$$

Where $\Re$ is is the photo-detectors responsivity, B is the electrical bandwidth of the receiver, $\mathrm{T_n}$ is the receiver noise temperature, $\mathrm{K_b}$ is Boltzmann constant and $\mathrm{R_1}$ Receiver load resistor Imtiaz et al. (2020),Garadi et al. (2017),Kandouci et al. (2017)
The captured power at the receiver P_{sr} , in the case of UWOC channel, is equivalent to P_{Rx}. Including thus, all the constraints of the underwater channel. From equations (1),(3),(4) and (5), the SNR of the studied system becomes:

$$\mathrm{SNR} = \frac{\left(\Re \cdot P_{Tx}\eta_{Tx}\eta_{Rx}\frac{A_{Rxeff}\cos(\varphi)}{2\pi d^2[1-\cos(\varphi_0)]}\exp\left[-c(\lambda)\frac{d}{\cos(\varphi)}\right]\cdot\frac{1}{\mathrm{L}}\right)^2}{2.\mathrm{e.B}.\Re \cdot P_{Tx}\eta_{Tx}\eta_{Rx}\frac{A_{Rxeff}\cos(\varphi)}{2\pi d^2[1-\cos(\varphi_0)]}\exp\left[-c(\lambda)\frac{d}{\cos(\varphi)}\right]\cdot\frac{1}{\mathrm{L}} + \frac{4\ \mathrm{K_b T_n B}}{\mathrm{R_1}}} \tag{6}$$

In order to investigate the OCDMA-UWOC studied system performances , it is necessary to evaluate the Bit Error Rate (BER). The relationship between the latter and the SNR depends closely on the modulation scheme chosen Akter et al. (2020). Various modulation techniques , are used in communications systems due their bandwidth efficiency, ease of implementation, and cost-effectiveness. The ones considered in this study are : non-return to zero on–off keying (NRZ-OOK), return to zero on–off keying (RZ-OOK) and Quadrature amplitude modulation (QAM).
BER can be expressed , by estimation from SNR , for different modulation schemes as follows Ali (2020) :

– for RZ-OOK Ali et al. (2020):

$$BER_{RZ-OOK} = \frac{1}{2}erfc\left[\frac{1}{2}\sqrt{SNR}\right] \tag{7}$$

– for NRZ-OOK Zou Wei et al. (2001)

$$BER_{NRZ-OOK} = \frac{1}{2} erfc\left[\frac{1}{2\sqrt{2}}\sqrt{SNR}\right] \tag{8}$$

– for M-QAM Mesleh et al. (2011):

$$BER_{M-QAM} = \frac{\sqrt{m}-1}{\sqrt{m}\log_2\sqrt{m}} erfc\left[\sqrt{\frac{3SNR}{2(m-1)}}\right] \tag{9}$$

Where M represents the level of the QAM.

5 Results and discussion

In this section , BER investigation of DD-OCDMA UWOC is presented for various modulation schemes (cited in section 4). The considered parameters are displayed in table 2 , considering a constant depth and no water turbulence.

Table 2 BER calculation parameters

Operating parameter	Value
Operating wavelength	575 nm
Transmitter efficiency η_{Tx}	0.8
Receiver efficiency η_{Rx}	0.8
Data bit rate	1 Gbit/s
Responsivity (Re)	0.6 (A/W)
Boltzmann constant (k_b)	$1.38 \times 10^{23}(JK)$
Temperature (T_n)	298 (K)
Load resistance (R_l)	1 KΩ
Transmission distance (d)	10 m
Transmitted power	500 mW
Effective aperture area of the receiver	0.01 m^2
Beam divergence angle (φ_0)	60°
Transmitter inclination angle (φ)	5°

Fig. 3 illustrates the bit error rate variation in function of the of number of active users considering a transmission power of $500mW$ and a code weight $\omega = 3$ for a $5m$ transmission distance (in clear water). It shows that the suitable 10^-9 BER is achievable for 12 active users using NRZ-OOK modulation , around 15 active users using RZ-OOK and 64-QAM modulation and up to 22 users using 16-QAM , making it the more suitable modulation format for the studied scheme.

In fig. 4, the same previous parameters are considered for different water types. In the case of a clear ocean, the suitable BER in only reachable for less than 10 users, and non achievable for a coastal ocean (due to the low value of the transmission power). Turbid water was not discussed in this study do it's

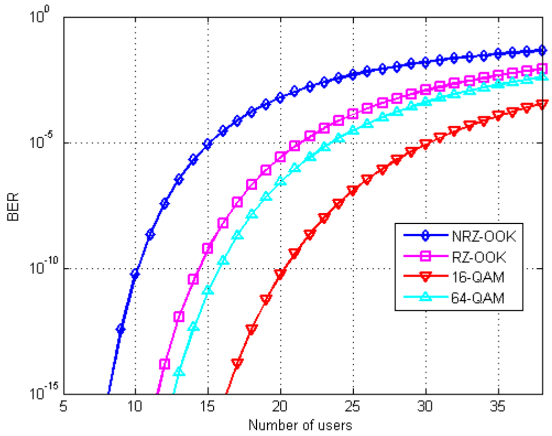

Fig. 3 BER versus number of users for clear water

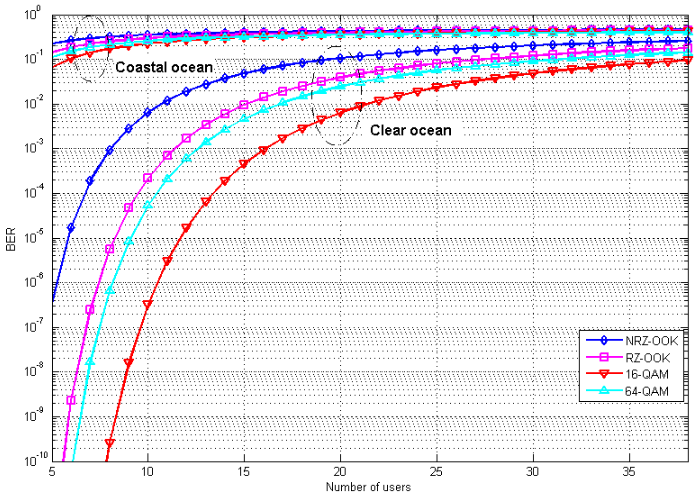

Fig. 4 BER versus number of users for clear and coastal ocean

high attenuation factor (as show in table 1).
It is demonstrated in Fig. 5 that the system performance and the increase in transmitted power have a direct positive correlation (which is translated by a decrease in the BER value). Indeed ,according to the water type and the spread of it's impurities , more power could be needed to overcome the optical attenuation induced my the channel.

We also studied the range effect by varying the transmission distance for different water types when the number of simultaneous users is 5 and transmitted power is 500 mW (see Fig 6. As in the previous cases , the BER depends

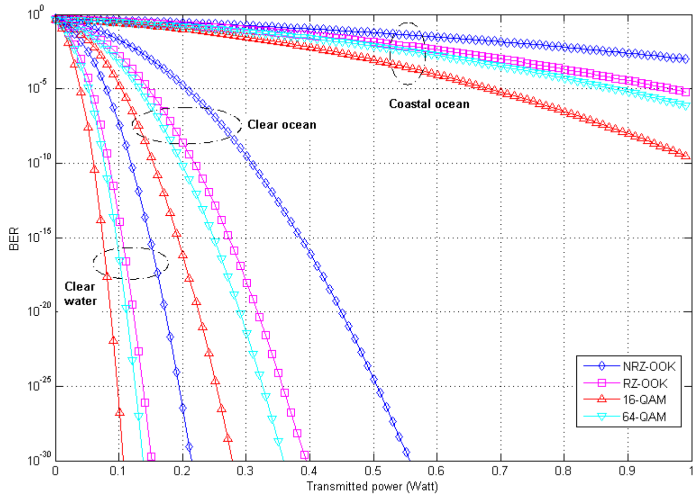

Fig. 5 BER versus transmitted power

strongly on the chosen water type. The maximum ranges with acceptable BER can be reached in for clear water ($26m$). 16-QAM also proved to be the more efficient modulation scheme. For other water types , the acceptable system performance can only be achievable for a range not exceeding $10m$ in coastal ocean and $15m$ for clear ocean.

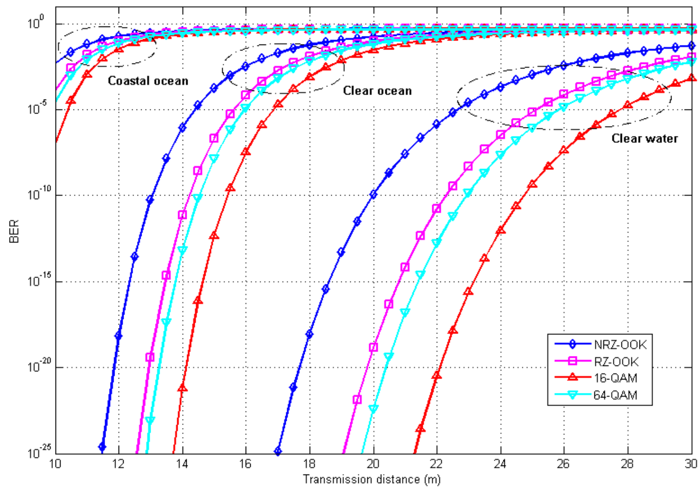

Fig. 6 BER versus transmission distance

In Fig. 7, the transmitter inclination angle (φ) is varying from 0° to 90° , for a 60 ° beam divergence angle (φ_0). φ , as shown previously Fig. 2, is defined by an angular value characterizing the deviation between the axis connecting the transmitter–receiver and the source's optical beam trajectory. Therefore, as reflected in Fig. 7, the system performances declines the source beam aligns away from the axis connecting the transmitter and the receiver.

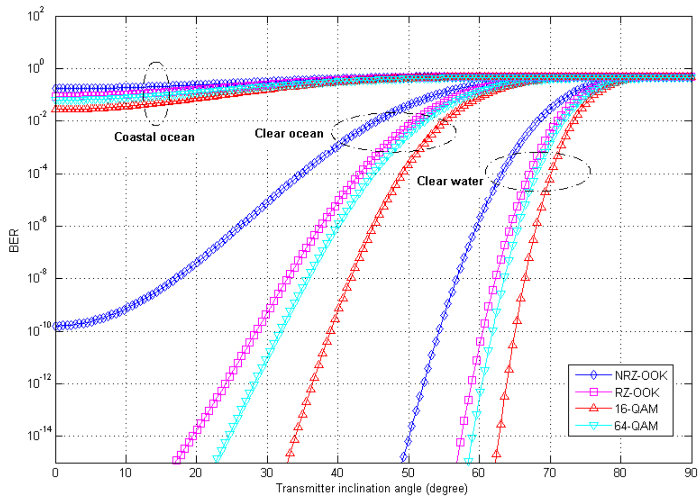

Fig. 7 BER versus transmitter inclination angle

The obtained results are in agreement with existing OCDMA-UWOC works in the literature Al Hammadi and Islam (2020) Yadav and Kumar (2020) with a simpler detection scheme and a significantly smaller captured power at the receiver. This is due to the ZCC codes properties. 16-QAM modulation was also determined to be the most effective in this study case.

6 Conclusion

In this paper , the UWOC-OCDMA system performances limitations were evaluated by referring to the bit error rate. In order to optimize the results , 4 different modulations techniques were considered (RZ-OOK , NRZ-OOK , 16-QAM and 64-QAM). The constraints considered in this study were the optical attenuation due to water particles and the detection of the lower acceptable power to reconstitute each user's data. Acceptable BER was achievable for a highest link distance of 26m.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

Not applicable

Competing interests

Not applicable

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Authors' contributions

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