



# Evaluation Performance of Two-Dimensional Multi-Diagonal Code Using Polarization and Wavelength of OCDMA System

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**Abstract**— In this paper, a new encoder/decoder technique has employed two orthogonal polarization states (vertical and horizontal) of a two-dimensional optical code, which combined polarization and wavelength scheme (p/w). This technique employed in order to increase the number of users in the FTTH network. In addition, Optical Fiber Systems (OFS) and Free Space Optics (FSO) scenarios were utilized with different Spectral Amplitude Coding Optical Code Division Multiple Access (SAC-OCDMA) codes. The FTTH network based on incoherent SAC-OCDMA is tested by using the One and Two Dimensional Multi-Diagonal (1D-MD, 2D-MD) codes and 1D and 2D Zero Cross Correlation (ZCC) codes. The results show that the number of the total supported homes for the 2D codes is doubled as a comparison with 1D codes. As well as, the simulation results show the performance of MD code is better presented than ZCC in both OFS and FSO scenarios.

**Keywords**— optical code division multiple access (OCDMA), Optical Fiber Systems (OFS), Free Space Optics (FSO), Multi-Diagonal (MD) code, Zero cross correlation (ZCC) code.

## I. INTRODUCTION

Optical networks system ensuring good performance for many of users and good quality access to services become the purpose objective of each operator. Optical CDMA (OCDMA) technique is the solution for future access of optical networks. OCDMA technique allows multiple simultaneous clients to share the same frequency and time interval [1]. The principle work of OCDMA based on concepts of the CDMA radiofrequency which is assigning to each user transmitting data through the transmission medium, where the code sequence identifies by the destination receiver [1]. In SAC-OCDMA technique, bandwidth content of a signal is coded by selective blocking of the spectral, which transfers it according to a code signature. SAC-OCDMA method is confident for an access environment in which cost is considered as one of the important factor [2].

A. Garadi has presented a new 2D encoder technique of SAC-OCDMA system based on two orthogonal polarization states in order to increase the number of simultaneous users. The authors have used ZCC code with only single weight. The theoretical results of this article show that the 2D ZCC OCDMA of the proposed system can multiplex the double number of users in comparison to the 1D ZCC OCDMA system [3].

A. Bouarfa et al has studied Phase-Induced Intensity Noise (PIIN) cancellation using a new receiving architecture

for spectral/spatial SAC-OCDMA system, where the PIIN is a drawback. There is a limitation to

increase users number in a 1D SAC-OCDMA system. Therefore, to overcome this limitation A. Bouarfa et al presented a new design of 2D wavelength/spatial system with using of single weight multi-diagonal (MD) in 2017. This architecture possesses the same features of 1D-MD code, which leads to entire cancellation of the MAI. Unlike traditional receivers that used in previous studies, where the suggested structure makes reducing in the system architecture not only eliminates PI-IN. The results have shown that the user's number achieved by the proposed system is the user number of the 1D system multiply by the couplers' number. In addition, the new proposed system has presented good performances at the high data rate [4].

To control the effect of the noises and MAI A. Cherifi et al. have developed a new design of a 2D wavelength/spatial code named two-dimensional Single Weight Zero Cross Correlation (2D-SWZCC) based on a single weight code which is characterized by a zero cross correlation and a high number of users. The simulation results show that the 2D-SWZCC code technique has good performance compared to the other systems using 2D-MD, 2D-PD, 2D-DCS, 2D-FCC/MDW, 2D-Extended-EDW, and 1D-SWZCC codes [5].

In this paper, to the best of our knowledge, we proposed a new approach of two-dimensional OCDMA combines polarization and wavelength (p/w) and simulated with two scenarios (OFS and FSO) by utilized different code techniques named Multi-Diagonal (MD), Zero Cross Correlation (ZCC) codes. Whereas these codes are selected due to mitigate and reduced the effect of Multi Access Interference (MAI) and PIIN in two scenarios, MAI is considered the most important factor of noise and interference in a SAC-OCDMA system. The results obtained by Optisystem V.7 and Matlab soft-ware. Section II presents the design of the 1D MD/ZCC codes. Section III presents the design of the 2D p/w OCDMA. Section IV contains the design and simulation the proposed architecture for 1D OCDMA system and 2D codes that increase the network users of OCDMA system. Section V provides the results and the discussion of the theoretical and the simulated systems that have been designed.

## II. ONE-DIMENSIONAL OCDMA DESIGN

The cross-correlation of any two different code sequences is given by [2]:

$$\lambda_c = \sum_{i=1}^L X_i Y_i \quad (1)$$

Where  $\lambda_c$  is the in-phase cross correlation, L is the code length,  $X = (x_1, x_2, \dots, x_L)$  and  $Y = (y_1, y_2, \dots, y_L)$  are the two code sequences. The most important parameters are the weight W (number of ones in each row) and  $\lambda_c$ , where they directly affect the Signal-to-Noise Ratio (SNR) of the overall system. The SNR (average signal power to noise power,  $SNR = I^2 / \sigma^2$ ) and the bit error rate (BER) are important equations to calculate the system performance of the 1D codes. Gaussian approximation is used to calculate BER, where  $\sigma_{th}$  is the thermal noise,  $\sigma_{sh}$  is the beat noise and  $\sigma^2$  is the variance of the optical detector [6]:

$$\sigma^2 = \sigma_{sh} + \sigma_{th} = 2eBI + \frac{4K_b T_n B}{R_L} \quad (2)$$

Where B is electrical bandwidth,  $T_n$  is absolute receiver noise temperature,  $K_b$  is Boltzmann's constant,  $R_L$  is receiver load resistance, I is mean of optic current and e is electron load.

Let  $C_k(i)$  is number of kth sequence of matrix of a code, where direct detection technique is used for a code properties and they are expressed as [4]:

$$\sum_{i=1}^L C_k(i) C_l(i) = \begin{cases} W, & \text{for } k = l \\ 0, & \text{Otherwise} \end{cases} \quad (3)$$

Power density of the received optic signal is given as follows:

$$G(v) = \frac{P_{sr}}{\Delta v} \sum_{k=1}^K d_k \sum_{i=1}^L C_k(i) C_l(i) \Pi(i) \quad (4)$$

Where K is the number of users,  $d_k$  is data bit of  $k_{th}$  user,  $P_{sr}$  is the effective received power of broadband source,  $\Delta v$  is the optical source bandwidth and  $\Pi(i)$  given by:

$$\Pi(i) = u \left[ v - v_0 - \frac{\Delta v}{2L} (-L + 2i) \right] - u \left[ v - v_0 - \frac{\Delta v}{2L} (-L + 2i + 2) \right] \quad (5)$$

Where

$$u(v) = \begin{cases} 1 & v \geq 0 \\ 0 & v < 0 \end{cases}$$

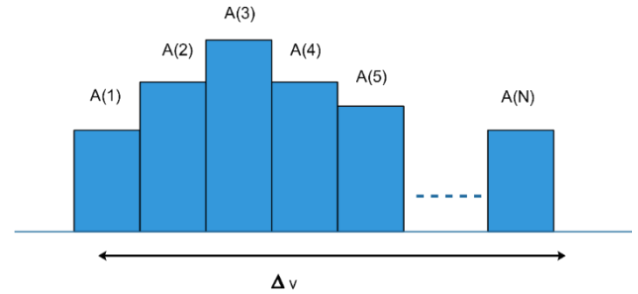


Fig. 1 The power spectral density of the received optic signal

To calculate  $G(v)$  integral, let consider an example of the power spectral density (PSD) first, as it is shown in Fig. (1), where  $A(i)$  is spectrum signal amplitude with width of  $\Delta v/L$ :

$$\int_0^\infty G(v) dv = \int_0^\infty \left[ \frac{P_{sr}}{\Delta v} \sum_{k=1}^K d_k \sum_{i=1}^L C_k(i) C_l(i) \Pi(i) \right] dv \quad (6)$$

$$\int_0^\infty G(v) dv = \frac{P_{sr}}{\Delta v} \int_0^\infty \left[ \sum_{k=1}^K d_k \cdot W \cdot \frac{\Delta v}{L} \right] dv \quad (7)$$

When all users send a bit simultaneously  $\sum_{k=1}^K d_k = d_1 + d_2 + d_3 + \dots + d_K = W$ , so

$$\int_0^\infty G(v) dv = \frac{P_{sr} W^2}{L} \quad (8)$$

The photocurrent I is given as

$$I = \Re \int_0^\infty G(v) dv \quad (9)$$

Where  $\Re$  is the photodiode responsivity, which can be given by  $\Re = \eta e / h\nu_c$ , and  $\eta$  is the quantum efficiency,  $\nu_c$  is the optical pulse central frequency of the original broad-band and  $h$  is Planck's constant. Equation (9) can be rewritten as:

$$I = \Re \int_0^\infty G(v)dv = \frac{\Re P_{sr}W^2}{L} \quad (10)$$

Substitute equation (10) into equation (2):

$$\sigma^2 = \frac{2eB \Re P_{sr}W^2}{L} + \frac{4K_bT_nB}{R_L} \quad (11)$$

Equation (11) can be written as follows if the transmitting probability of 0.5 is taken into account for each bit 1 at any time per user:

$$\sigma^2 = \frac{eB \Re P_{sr}W^2}{L} + \frac{4K_bT_nB}{R_L} \quad (12)$$

Hence, SNR and BER of the direct detection technique can be expressed as [7]:

$$SNR = \frac{I^2}{\sigma^2} = \frac{\left(\frac{\Re P_{sr}W^2}{L}\right)^2}{\frac{eB \Re P_{sr}W^2}{L} + \frac{4K_bT_nB}{R_L}} \quad (13)$$

$$BER = \frac{1}{2} \operatorname{erfc} \left( \sqrt{\frac{SNR}{8}} \right) \quad (14)$$

Where *erfc* is the function of complementary error.

#### A) Multi-diagonal (MD) code

The MD code is characterized by the (L, W, λc) parameters to construct a diagonal matrix of size (K × L). Assume I<sub>k</sub> the identity matrix (K × K):

$$I_1 = [1], I_2 = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}, \dots, I_K = \begin{bmatrix} 1 & 0 & \dots & 0 & 0 \\ 0 & 1 & 0 & \ddots & 0 \\ \vdots & 0 & \ddots & 0 & \vdots \\ 0 & \ddots & 0 & 1 & 0 \\ 0 & 0 & \dots & 0 & 1 \end{bmatrix} \quad (15)$$

So, we can get zero by using cross-correlation equation (1) between any two rows of I<sub>k</sub>.

The MD matrix has constructed from the sequences repetition of a diagonal matrix, where w represented number of repetition.

For example of an MD matrix with four users and weight is three, since K=5 and W=3 the length of the MD code is given by L= K × W [8], where L here is 15 and the code word is:

$$MD_{code} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}_{5 \times 15} \quad (16)$$

$$codewords = \begin{cases} user1 & \Rightarrow \lambda_1, \lambda_{10}, \lambda_{11} \\ user2 & \Rightarrow \lambda_2, \lambda_9, \lambda_{12} \\ user3 & \Rightarrow \lambda_3, \lambda_8, \lambda_{13} \\ user4 & \Rightarrow \lambda_4, \lambda_7, \lambda_{14} \\ user5 & \Rightarrow \lambda_5, \lambda_6, \lambda_{15} \end{cases} \quad (17)$$

#### B) Zero cross-correlation (ZCC) code

The ZCC code has been designed to solve the MAI problem and terminate the effect of the PIIN, which are considered the major causes of the SNR limitation. Hence, leading to much better BER performance. The balanced incomplete block design (BIBD) algorithm is used to construct 1D ZCC [3]. It is essential to note that the determination of number of users K is based on the following equation [9], [10]:

$$(K - 1) + (W - 1) \times K \leq L \Rightarrow K \leq \frac{L+1}{W} \quad (18)$$

Moreover, the position of the each “1” is specified by:

$$P_m = \alpha^{(i+jK)} \operatorname{mod} C \quad (19)$$

With

$$0 \leq i \leq (K - 1), 0 \leq j \leq (W - 1)$$

Where C is the prime number and α is the primitive root of C. As example, for L=12, W=3, and K=4 the code is:

$$ZCC_{code} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (20)$$

### III. TWO-DIMENSIONAL OCDMA DESIGN

According to what we has mentioned before and in order to apply 1D-OCDMA's there are some disadvantages in those codes, such as limited allowed number of users and large bandwidth consumption. Therefore, two dimensional optical code multiplexing encoding and decoding OCDMA system (2D-OCDMA) has been investigated to solve these limitations by spreading the code into two different domains (polarization/spectral). In order to generate 2D-OCDMA will utilize an existing 1D coding technique in a combined polarization and wavelength scheme (p/w). In 2D coding structure, each user is specified by a different wavelength and different orthogonal polarization angle depending on the same codes of 1D that discussed before in section II. Therefore, the number of users will be double if two orthogonal polarization states have been used with the same spectral signature, as shown in the equation (23). In this paper, to generate two polarization axes at 0° and 90° a

polarization beam splitter will be used after the optical source as shown in Fig (2).

$$K_{2D} = 2 \times K_{1D} \quad (23)$$

Since, wavelengths will be used twice ( $\lambda^{\parallel}$  and  $\lambda^{\perp}$ ) the power spectral density will be doubled; therefore, equation (4) can be rewritten as:

$$G(v) = \left[ \frac{P_{sr}}{\Delta v} \sum_{k=1}^K d_k \sum_{i=1}^L C_k(i) C_i(i) \cdot \Pi(i) \right] \cdot (\cos \theta + \sin \theta) \quad (24)$$

Moreover, it can be expressed that the integral of the power spectral density as:

$$\int_0^{\infty} G(v) dv = \frac{P_{sr}}{\Delta v} \int_0^{\infty} \left[ \sum_{k=1}^K d_k \sum_{i=1}^L C_k(i) C_i(i) \cdot \frac{\Delta v}{L} \right] \cdot (\cos \theta + \sin \theta) dv \quad (25)$$

$$\int_0^{\infty} G(v) dv = \left[ \frac{P_{sr}}{L} \sum_{k=1}^K d_k \sum_{i=1}^L C_k(i) C_i(i) \right] \cdot (\cos \theta + \sin \theta) \quad (26)$$

$$\int_0^{\infty} G(v) dv = \left[ \frac{P_{sr}}{L} \sum_{k=1}^K d_k \cdot W \right] \cdot (\cos \theta + \sin \theta) \quad (27)$$

Therefore, when all users send a bit simultaneously the summation  $\sum_{k=1}^K d_k = d_1 + d_2 + d_3 + \dots + d_K = W$ , as long as we assume that the single weight code has been used. The power spectral density integration will be:

$$\int_0^{\infty} G(v) dv = \frac{P_{sr}}{L} \cdot (\cos \theta + \sin \theta) \quad (28)$$

Then, by substituting the equation (28) into the equation (9) of photocurrent for each polarization states:

$$I = \frac{\eta e}{h \nu_c} \int_0^{\infty} G(v) dv = \frac{\eta e}{h \nu_c} \cdot \frac{P_{sr}}{L} \quad \text{if } \theta = 0^\circ \text{ or } \theta = 90^\circ \quad (29)$$

Hence, by using equations (2 & 29) the SNR and BER relations of the direct detection technique of 2D system can be determined as [11]:

$$SNR = \frac{I^2}{\sigma^2} = \frac{\left( \frac{\eta e \cdot P_{sr}}{h \nu_c \cdot L} \right)^2}{2 \cdot \frac{\eta e^2 \cdot P_{sr} \cdot B}{h \nu_c \cdot L} + \frac{4 K_b T n B}{R_L}} \quad (30)$$

$$BER_{2D} = \frac{1}{2} \operatorname{erfc} \left( \sqrt{\frac{\left( \frac{\eta e \cdot P_{sr}}{h \nu_c \cdot L} \right)^2}{8 \cdot \left( 2 \cdot \frac{\eta e^2 \cdot P_{sr} \cdot B}{h \nu_c \cdot L} + \frac{4 K_b T n B}{R_L} \right)}} \right) \quad (31)$$

#### IV. SYSTEM DISCRIPTION

The proposed design of three or four residence buildings with different code techniques (1D-2D MD and 1D-2D ZCC) by using OFS and FSO are described in this section as shown in Figures (2, 3) at the end of this article. We have used wavelength division multiplexer (WDM) to encode the light as amplitude-spectrally according to a certain code. The data of each user, which generated by pseudo random bit sequence (PRBS) and using non-return to zero (NRZ) pulse generator, is optically modulated by optical external modulator (Mach-Zehnder modulator) on a light into code sequence at the transmitter through a splitter into a Fiber Bragg Grating (FBG) filter that acts as decoder, where direct detection is used for MD and ZCC codes as shown in Figures (2, 3). To detect output signal, PIN photodetector has been used to convert it to an electrical signal. Finally, the electrical signal passes through a low-pass filter (LPF) to retrieve the original information.

For 2D (p/w) encoder, the difference to the 1D encoder is that a polarization splitter used to split the light signal into two signals and rotate one of them by polarization angle of  $90^\circ$ . Hence, two angles of polarization of the light signal will end. The Mach-Zehnder, which is based on an interferometric principle acts as an intensity modulator. The light source that is utilized in the proposed system is a white light source. It has broad optical bandwidth (usually equal or more than 100 nm). Finally, users' modulated code sequences are combined together and transmitted through the channel. At the receiving side, the optical signal passes be created as in Fig. (2). In the receiving side, the power splitter and polarization attenuator have been utilized to separate the polarization.

In this work, two scenarios have been utilized for the channel. The first one is single mode fiber as an appropriate transmission media for FTTH networks where low attenuation and dispersion is required. Different lengths of a standard single mode fiber (SSMF) have been used with polarization mode dispersion (PMD) of  $32 \text{ ps}/\sqrt{\text{km}}$ , dispersion of  $16.75 \text{ ps/nm/km}$ , dispersion slop  $0.075 \text{ ps/nm}^2/\text{km}$ , attenuation coefficient of  $0.2 \text{ db/km}$  and non-linearity refractive  $2.6 \times 10^{-20} \text{ m}^2/\text{W}$ .

The second scenario of the transmission media is the FSO. This system is considered a good solution for such a last mile connection which using an optical fiber cable is difficult, where in FSO a light is traveling through the atmosphere instead of fiber. As well as, FSO system has other advantages like the initiation cost, deployment time and low maintenance cost.

FSO system has some constraints such as Line of Sight (LoS) and attenuation. The atmospheric conditions like fog, rain, haze, hot and dry cause the attenuation, absorption and scattering [12], [13].

#### V. PERFORMANCE ANALYSIS OF OCDMA SYSTEM

According to equations (14 and 31), the BER of one and two dimensional of the MD and ZCC codes have been achieved mathematically under conditions of 622 Mbps, power spectral density ( $P_{sr} = -10$  dBm), weight ( $W = 4$ ), and the number of users,  $K$ , up to 200. The parameters of equations (14 and 31), that are used to find out the numerical calculation are listed in Table 1, the results have obtained by using Matlab software. The BER versus number of user are shown in Fig. (4), which clarifies that (for the maximum acceptable value of BER  $10^{-9}$ ) the number of the total supported of users for the 2D codes is doubled in compression with 1D codes.

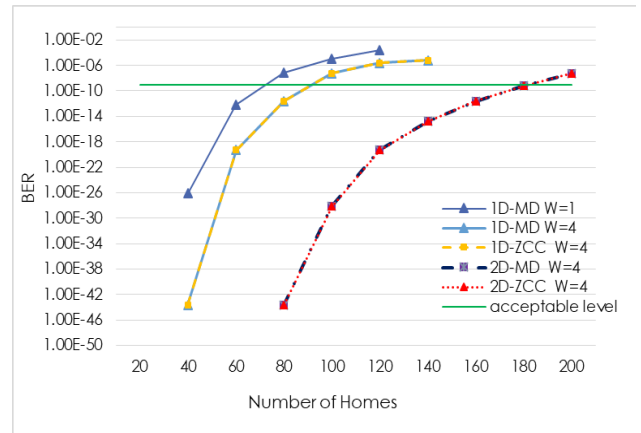


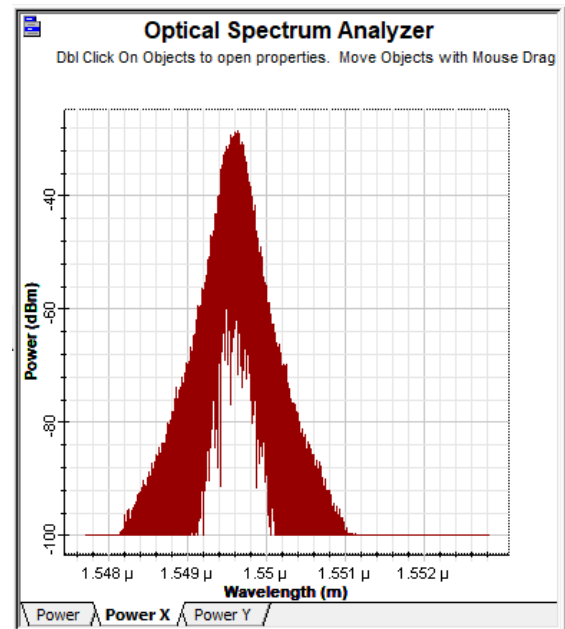
Fig. 4 Comparison BER performance versus number of users for 1D-2D MD and 1D-2D ZCC Codes

TABLE I  
Typical Analysis Parameters

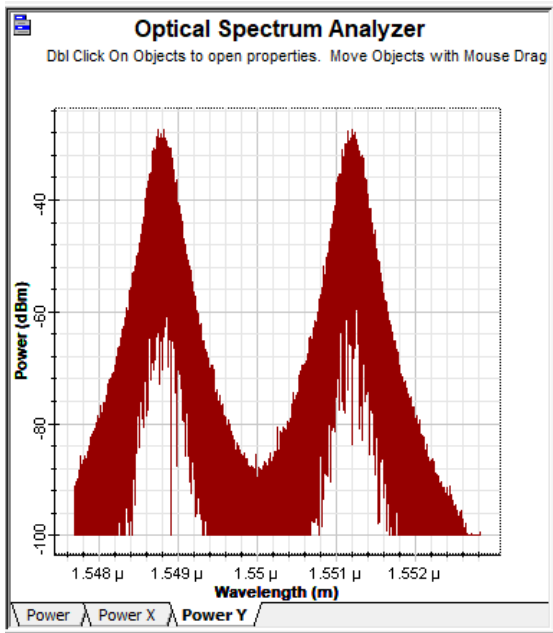
Symbol	Parameter	Value
$v_c$	Operating wavelength	1550 nm
$\Delta\nu$	Linewidth broadband source	3.75 THz
$P_{sr}$	Broadband effective power	-10 dBm
$B$	Electrical bandwidth	311 MHz
$T_n$	Receiver noise temperature	300 K
$\eta$	Photodetector quantum efficiency	0.6
$R_L$	Receiver load resistor	1030 $\Omega$
$h$	Planck's constant	$6.66 \times 10^{-34}$ Js
$e$	Electron charge	$1.6 \times 10^{-19}$ C
$K_b$	Boltzmann's constant	$1.38 \times 10^{-23}$ J/K

Meanwhile, the MD codes show the same performance compared to the ZCC codes. This behaviour because the only difference between those codes is the arrangement of the ones where both codes give better performance with comparison to other types of SAC-OCDMA codes [14],[15]. In addition, Figure (4) shows that the higher number of weight, the better performance of the system as this can be seen with 1D-MD  $W=1$  compared to 1D-MD  $W=4$ . It must be taken into account that this increase of the weight will make the encoder and decoder more complex.

Figure (5) demonstrates a sample of the optical spectrum of 2D code (polarization/wavelength) with weight equal to three. The difference between (a) and (b) is  $90^\circ$  of polarization angle. The weight is divided into two angles of polarization (X and Y) where this allows the reusing of those wavelengths another once by other codes.



(a)



(b)

Fig. 5 Optical spectrum of a 2D (polarization/wavelength) code with  $W=3$

Figure (6) indicates to the relationship between the 1D MD, 1D ZCC, 2D MD and 2D ZCC Codes and distances in the single mode OFS with taking into account the effects of attenuation, dispersion and nonlinearities. It also shows that 2D codes are more vulnerable to attenuation and dispersion in single-mode optical fiber cables and the performance of the one-dimensional codes is much better presented compared with two-dimensional codes. This is due to the differential group delay (DGD), PMD, additional noise and power dissipation of the extra devices in the system of 2D OCDMA. However, with this white light source and for 25 Km of fiber reaching about 10-20 of BER of 2D codes is quite enough for FTTH network. While Figure (7) indicates to the relation between the SAC-OCDMA codes and distances in the FSO system at a heavy rain condition. The performance of 2D OCDMA is closer to the 1D OCDMA in this scenario. Additionally, for short distances, the power received does not have a powerful effect on the performance and quite the opposite of this in the large distances.

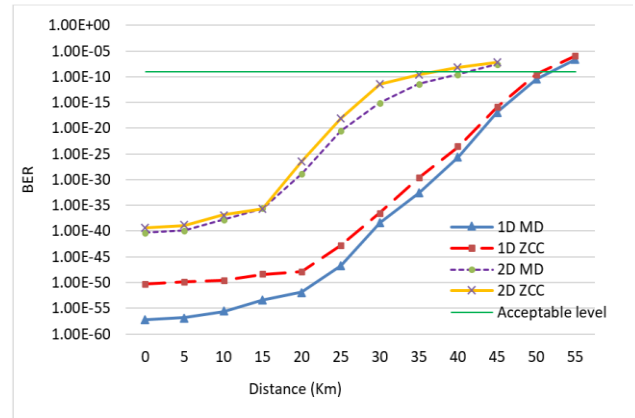


Fig. 6 BER versus Distance for 1D MD, 1D ZCC, 2D MD and 2D ZCC Codes with  $K=3$  and  $W=3$  in OFS Scenario

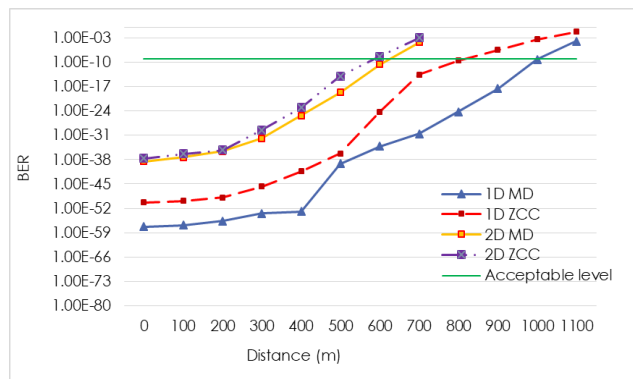
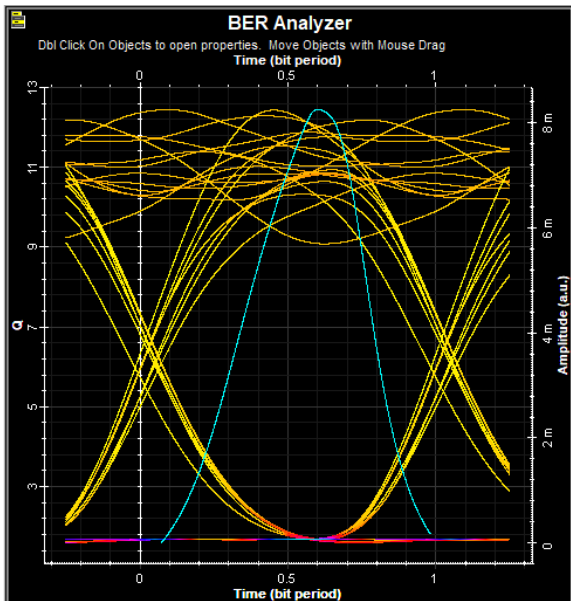


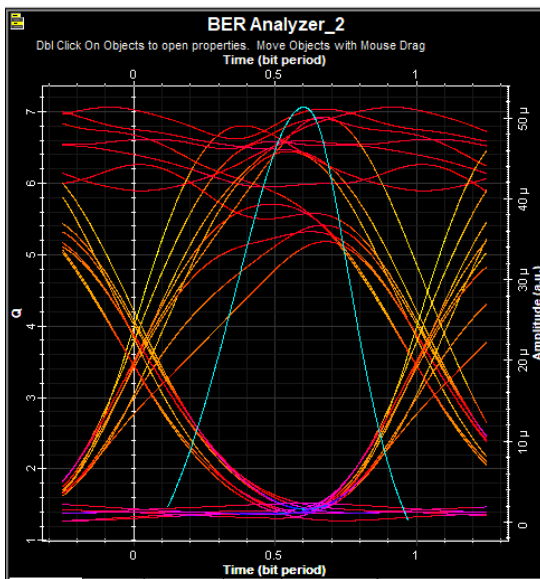
Fig. 7 BER versus Distance for 1D MD, 1D ZCC, 2D MD and 2D ZCC codes with  $K=3$  and  $W=3$  in FSO Scenario under Heavy Rain Condition

From Figures (6, 7), it is noted that the MD code presented better performance than ZCC code in spite of the fact that both of them have the same code length and weight. This is due to the MD code has depended on the unity matrix only and has less susceptibility to turbulence effect.

Figure (8) shows that the 2D-MD at 10 Gbps (with CW laser source) eye diagrams and the 2D-MD at 622 Mbps (with white light source) respectively with  $W=2$ ,  $K=4$  and 500m of distance at the FSO scenario. It can be noted that the 2D-MD with source of CW laser system gives better performance than 2D-MD with white light source system where the narrower eye diagram, even the first system has much higher data rate. This behaviour is due to the level of power spectral density that depends on the optical bandwidth range of the light source, which is broad optical bandwidth in the white light source on the contrary of CW laser source that has a low Linewidth. In the eye diagram, closer eye leads to hard distinguish between ones and zeroes of the received signal.



(a)



(b)

Fig. 8 Eye Diagram of the 2D-MD code with  $W=2$ ,  $K=4$  and distance of 500 m in the FSO Scenario at bit rates: (a) 10 Gbps and (b) 622 Mbps

## VI. CONCLUSIONS

A new architecture of 2D-MD/ZCC OCDMA system, can reduce the effect of MAI and PIIN, based on polarization/wavelength is successfully designed and simulated, where two polarization angles have been used as a second dimension. The theoretical results of 2D p/w MD and ZCC

optical codes provide double number of customers' homes in comparison to 1D optical coding in the FTTH network, also this results show that the higher number of weight the better performance of the system. This can be seen in 1D-MD  $W=1$  compared to 1D-MD  $W=4$ . Zero-cross correlation codes have been chosen in this paper because they give better performance with comparison to other types of SAC-OCDMA codes like low-cross correlation codes. The simulation results of three OCDMA customers' homes using MD and ZCC in both OFS and FSO scenarios along different distances have shown that the performance of MD code is a better presented than ZCC, where both MD and ZCC are zero-cross correlation codes. This behaviour is attributed to the fact that the OCDMA codes performance depend on media. These results also show that 2D codes are more vulnerable to attenuation and dispersion in single-mode optical fiber cables and the performance of the 1D codes is a better presented compared with 2D codes along the optical fiber; this is due to the additional noise and power dissipation of the extra devices in the system of 2D p/w OCDMA. However, with broadband white light source and for 25 Km of fiber reaching about 10-20 of BER of 2D codes is quite enough for FTTH network. According to those studies, it certain that the 2D-MD p/w code is the best choice for scalable FTTH networks.

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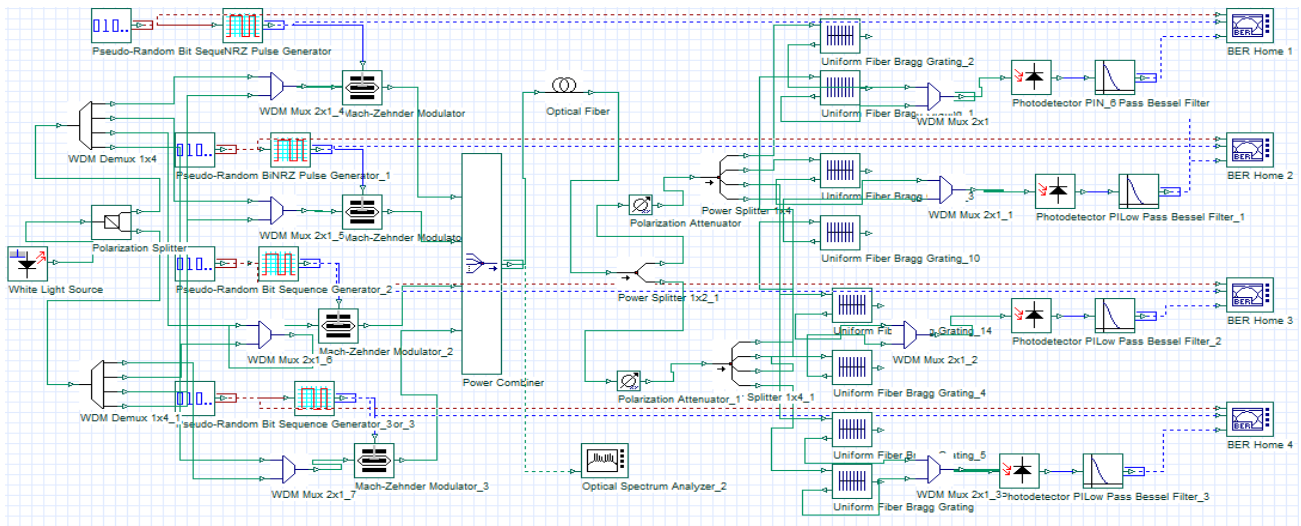


Fig. 2 Schematic block diagram of the 2D-MD/ZCC codes with SMF, K=4 and W=2



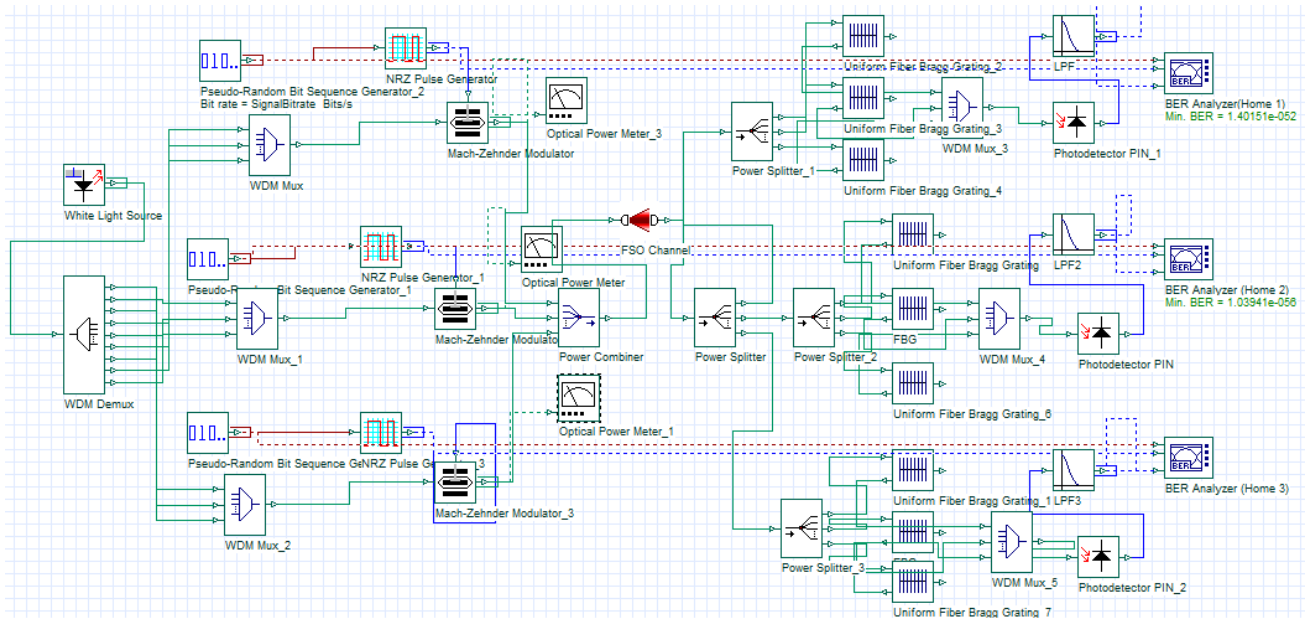


Fig. 3 FSO system with 1D-MD/ZCC codes, K=3 and W=3