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Performance analysis of spectral/spatial of OCDMA system using 2D hybrid ZCC/MD code

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ABSTRACT

This paper proposes a new spectral/spatial code for Spectral Amplitude Coding in Optical Coding Division Multiple Access (SAC-OCDMA) called two-Dimensional hybrid ZCC/MD code. The new code combines two of the one –dimensional codes which are Zero Cross Correlation (1D ZCC) and Multi-Diagonal code (1D MD). Moreover, it produces a zero cross correlation property for each code. The main goal of this proposed code is to mitigate Phase Induced Intensity Noise and eliminate Multiple Access Interference (MAI). This proposed code can provide a better performance comparing to other codes as 2D FCC/MDW and 2D DPDC according to the obtained numerical analysis.

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1. INTRODUCTION

The key goal in developing Optical Code Division Multiple Access (OCDMA) is to overcome some disadvantages in a communication network through optical fiber such as low-security level when multiple users access the same bandwidth, low rate transmitting speed, and complexity designing. OCDMA with its characteristic offers a lot of advantages as asynchronous and simultaneous access of multiple users to the network, broadband access and low losses, the transmission with high level of security and facilitation of the realization of many services so OCDMA has been introduced to respond to many requirements in optical fiber communication [1]. OCDMA system can be classified on coherent and incoherent based on the property of its respective optical signal [2], many schemes have been proposed where Spectral Amplitude Coding is one of these schemes (SAC-OCDMA) [3, 4]. SAC-OCDMA has been attracted from a huge research according to its features but it can be affected by many factors such as Phase Induced Intensity Noise (PIIN) and Multiple Access Interference (MAI) which are the main challenges of OCDMA system [5, 6]. To achieve this goal two-dimensional codes are developed to overcome deficiencies of one-dimensional codes which are introduced as 2D Diluted Perfect Difference (2D DPD) [7], 2D Modified Double Weight (2D MDW) [8, 9], 2D hybrid code FCC/MDW [10], 2D Dynamic Cyclic Shift code (2D DCS) [11]. In this paper, the proposed code 2D ZCC/MD is developed to mitigate PIIN and suppress MAI to attain high performance. The current paper is arranged as follow, the second section focuses about 2D ZCC/MD construction combining 1D MD [12] and 1D ZCC [13, 14]. The third section describes results and discussion. Finally, the fourth section the conclusion of this study.

2. HYBRID ZCC/MD CODE

Based on the combination of 1D MD [12] and 1D ZCC [13, 14] 2D ZCC/MD is constructed. 2D ZCC/MD code denoted by $(M \times N, k, \lambda_a, \lambda_c)$ where $M \times N$ represents code size of 2 D ZCC/MD, k is code weight, λ_a, λ_c represent auto and cross correlation respectively. Let $Y\{y_0, y_1, y_2, \dots, y_{N-1}\}$ and $X\{x_0, x_1, x_2, \dots, x_{M-1}\}$ represent 1D-MD code and 1D ZCC code sequences respectively. Some examples for 2d ZCC/MD sequences are shown in Table 1 for $k_1 = 3, k_2 = 2$. 2D hybrid ZCC/MD codes can be created by $g = \{1,2,3, \dots, M\}$ and $h = \{1,2,3, \dots, N\}$. X_h represents the patterns for space, Y_g represents spreading patterns of spectral.

$$ZCC = \begin{bmatrix} 101000100000 \\ 010010001000 \\ 000000010101 \end{bmatrix} \quad MD = \begin{bmatrix} 100001 \\ 010010 \\ 001100 \end{bmatrix}$$

Table 1. Example of 2-D ZCC/MD Code Sequences for $k_1 = 3$ and $k_2 = 2$

$A_{g,h}$	[101000100000]	[010010001000]	[000000010101]
$\begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$	$\begin{bmatrix} 101000100000 \\ 000000000000 \\ 000000000000 \\ 000000000000 \\ 000000000000 \\ 101000100000 \end{bmatrix}$	$\begin{bmatrix} 010010001000 \\ 000000000000 \\ 000000000000 \\ 000000000000 \\ 000000000000 \\ 010010001000 \end{bmatrix}$	$\begin{bmatrix} 000000010101 \\ 000000000000 \\ 000000000000 \\ 000000000000 \\ 000000000000 \\ 000000010101 \end{bmatrix}$

The derivation of cross-correlation of the 2D ZCC/MD code is based on four matrices of features $A(d)$, $d \in (0,1,2,3)$ is introduced by KERAF, et al. (2016)[10]. Following similar assumption, the cross correlation feature as $A\ (d)$ can be depicted as follows:

$$A^0 = Y^T X \tag{1}$$

$$A^1 = Y^T \bar{X} \tag{2}$$

$$A^2 = \overline{Y^T} X \tag{3}$$

$$A^3 = \overline{Y^T X} \tag{4}$$

$\bar{X}$, $\bar{Y}$ parameters represent X & complementary respectively. The 2D hybrid ZCC/MD code cross correlation $A^{(d)}$ and $A_{g,h}$ is shown as follow:

$$R^{(d)}(g,h) = \sum_{M=1}^{M-1} \sum_{N=1}^{N-1} a_{ij}^{(d)} a_{(i+g)(j+h)} \tag{5}$$

Wherever $a_{ij}^{(d)}$ represents the $(i,j)_{th}$of $A^{(d)}$ and $a_{(i+g)(j+h)}$ is the $(i,j)_{th}$ of $A_{g,h}$. 2D ZCC/MD code cross correlation given by the (5) can be described on the Table 2.

Table 2. Cross-Correlation of 2D Hybrid ZCC/MD Code

$A_{g,h}$	$R^{(0)}$	$R^{(1)}$	$R^{(2)}$	$R^{(3)}$
$g = 0, h = 0$	$k_1 k_2$	0	0	0
$g = 0, h \neq 0$	0	$k_1 k_2$	0	0
$g \neq 0, h = 0$	0	0	$k_1 k_2$	0
$g \neq 0, h \neq 0$	0	0	0	$k_1 k_2$

The cross correlation of $A_{0,0}^{0}$ and $A_{g,h}$ can be written:

$$\begin{aligned} R^{(0)}(g,h) &= \sum_{i=1}^{M-1} \sum_{j=1}^{N-1} a_{i,j}^{(0)} a_{i,j}(g,h) \\ &= \begin{cases} k_1 k_2 & for\ g = 0, h = 0 \\ 0 & otherwise \end{cases} \end{aligned} \tag{6}$$

According to the Gaussian approximation, BER is calculated. The photodiode is used to obtain the photocurrent and to detect thermal lights as in [15, 16]:

$$\begin{aligned}\langle i_{noise}^2\rangle &= \langle i_{PIIN}^2\rangle + \langle i_{shot}^2\rangle + \langle i_{thermal}^2\rangle \\ &= BI^2\tau + 2eBI + \frac{4K_bT_nB}{R_L}\end{aligned} \tag{7}$$

e represents electron's charge, K_b is constant of Boltzmann, I stands for the average photocurrent, R_L is the load resistance, T_n is the unlimited temperature, B means the electrical bandwidth. The 2D ZCC/MD code system represents a property of zero cross correlation, so the impact of Multiple Access Interference has been removed. Add on, adapting the same process as [12] where the probability of distributing bit 1 for each user is equal. At the receiver (0,0), the output currents is count on the cross-correlation of $A_{0,0}^{(0)}$ and $A_{g,h}$ as:

$$\begin{aligned}I &= R\int_0^\infty G(v)dv \\ &= \int_0^\infty \frac{P_{sr}}{k_2\Delta v}\sum_1^w d(w)R^0(i,j)U(v,i)dv\end{aligned} \tag{8}$$

$$\begin{aligned}&= \frac{P_{sr}\,\Delta v}{k_2\Delta vM}\left[k_1k_2 + \sum_1^w d(w)R^0(i,j)\right] \\ &= \frac{RP_{sr}k_1}{M}\end{aligned} \tag{9}$$

The expression of equations for Shot noise, PIIN and Thermal noise could be expressed as below:

$$\langle i_{shot}^2\rangle = 2eB\,\frac{RP_{sr}w_2}{W} \tag{10}$$

$$\langle i_{PIIN}^2\rangle = B\,\frac{R^2P_{sr}^2w_2k_1}{\Delta vW} \tag{11}$$

$$\langle i_{thermal}^2\rangle = \frac{4K_bT_nB}{R_L} \tag{12}$$

So:

$$\langle i_{noise}^2\rangle = 2eB\,\frac{RP_{sr}w_2}{W} + \frac{R^2P_{sr}^2w_2k_1}{\Delta vW} + \frac{4K_bT_nB}{R_L} \tag{13}$$

Where:
P_{sr}: effective source power at the receiver,
R: The responsivity,
k_1: The code weight for spectral sequences,
k_2: The code weight for spec spatial sequences,
W: The number of simultaneous clients,
N: lengths of spatial code sequences,
M: length of spectral code sequences.

Remark: at a different time, the probability of sending bit "1" for every user at a different time is being ½ so:

$$\langle i_{noise}^2\rangle = \frac{eBRP_{sr}w_2}{W} + \frac{R^2P_{sr}^2w_2k_1}{2\Delta vW} + \frac{4K_bT_nB}{R_L} \tag{14}$$

The SNR at the receiver can be written as follow:

$$\mathrm{SNR} = \frac{\mathrm{I}^2}{\langle \mathrm{i}_{noise}^2\rangle} = \frac{\left[\frac{\mathrm{RP_{sr}w_2}}{\mathrm{W}}\right]^2}{\frac{\mathrm{R^2P_{sr}^2w_2k_1}}{2\Delta \mathrm{vW}} + \frac{\mathrm{eBRP_{sr}w_2}}{\mathrm{W}} + \frac{4\mathrm{K_bT_nB}}{\mathrm{R_L}}} \tag{15}$$

From SNR the BER can be derived as depicted [17]:

$$BER = \frac{erfc\left(\sqrt{SNR/8}\right)}{2} \quad (18)$$

Wherever

$$erfc = \frac{2}{\sqrt{\pi}} \int_0^\infty \exp(-y^2)dy \quad (19)$$

The listed parameters that applied for analysing the effect of 2D ZCC/MD on the OCDMA performance is shown in Table 3. The following figures depict the analytical results.

Table 3. The Parameters Employed in Numerical Calculations

Spectral width of broadband light source	$\Delta\lambda = 300nm(\Delta\lambda = 3.75THZ)$
PD quantum efficiency	$R = 0.75$
Operating wavelength	$\lambda_0 = 1.55\mu m$
Data transmission rate	$R_b = 622Mbps$
Electrical bandwidth	$B = 320MHz$
Receiver load resistor	$R_L = 1030\Omega$
Receiver noise temperature	$T_n = 300K$
Electron's charge	$e = 1.60217646 \times 10^{-19} coulombs$
Constant of Boltzmann	$K_b = 1.38 \times 10^{-23}\ W/K/\ Hz$

3. RESULTS AND DISCUSSIONS

Figure 1 represents BER versus number of simultaneous user when the received effective power $Psr = 10^{-2}\ watt$ and data rate $622\ Mbps$ for proposed code 2D ZCC/MD (M=23, N=7) comparing with 2D DPDC (M=91, N=3) and 2D FCC/MDW (M=23, N=7). It is clear that 2D ZCC/MD can accommodate 360 active user at the BER equal to 10^{-9} where the other code accommodate less than 100 user. 2D ZCC/MD represents a better performance compared with other codes.

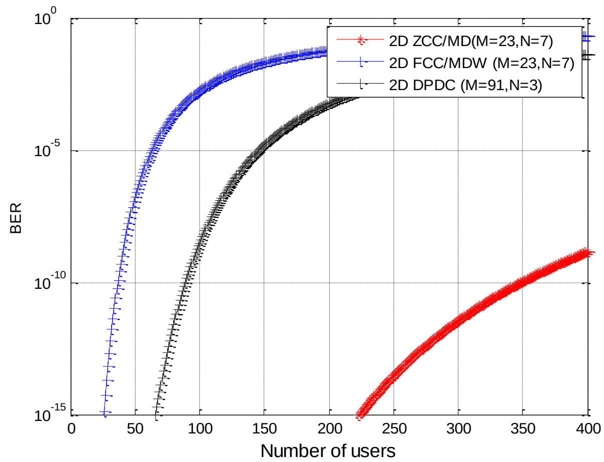

Figure 1. BER versus number of users when $Psr = 10^{-2}\ watt$ and data rate $Rb = 2.5GHZ$ comparison with 2D codes FCC/MDW and 2D DPDC

Figure 2 represents the plot of BER versus effective power P_{sr} of the new code 2D ZCC/MD (M=23, N=7) comparing with 2D DPDC (M=91, N=3) and 2D FCC/MDW (M=23, N=7) when number of user equal to 150 and data rate $Rb = 622Mbps$ for every client. It is obvious that when P_{sr} is less than $-25\ dBm$, all codes exhibited poor performance where their BER are higher than 10^{-9}domination of noise power represented by thermal noise on the signal power. When the received power increases above $-25\ dBm$, the performance of these codes gradually improve with the power. 2D ZCC/MD exhibit superior performance compared with other codes, where the BER value at $-10\ dBm$ is 10^{-25} compared to 10^{-6}

For 2D FCC/MDW and 10^{-6} For 2D DPDC. The figure proves that whenever the received power increases, the behavior of 2D ZCC/MD is better than others.

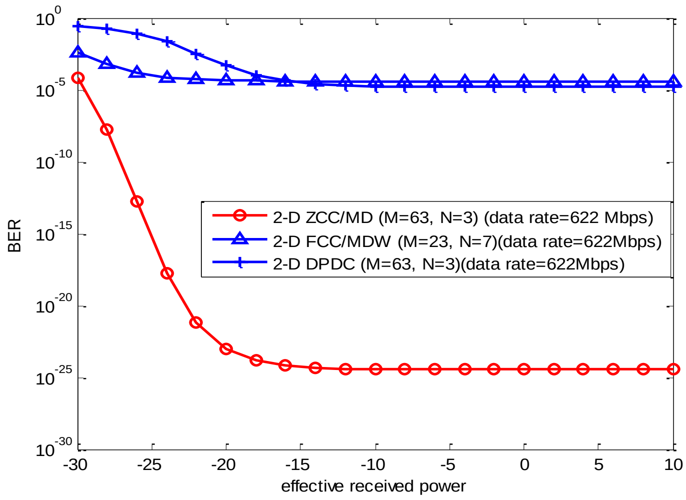

Figure 2. BER versus effective power when data rate $Rb = 622Mbps$ and number of user $K = 150$

Figure 3 represents BER versus effective power for 2D ZCC/MD with different data bit rate when it's equal to $622\ Mbps$, $1.25Gbps$ and $2.5Gbps$. At BER equal to 10^{-9} 2D ZCC/MD require -25dBm for $Rb = 622Mbps$ while for $Rb = 1.25Gbps$ the effective power equal to -22dBm. it can be clear that when data rate is equal to 622Mbps represent a better performance comparing with other value of data rate.

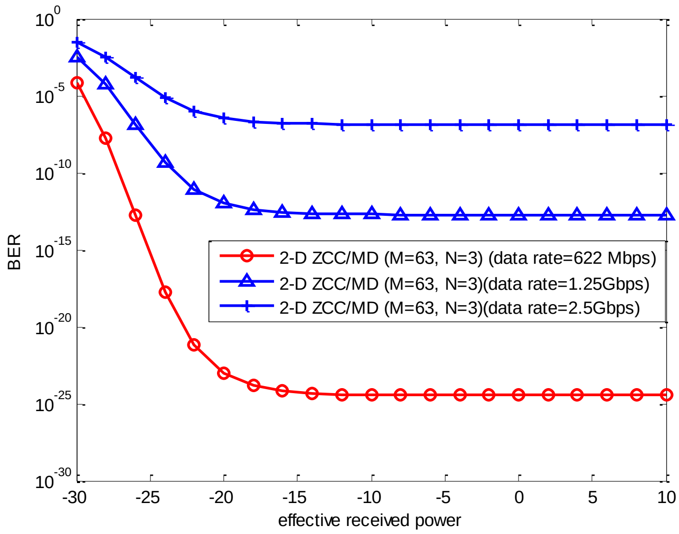

Figure 3. BER versus effective power when data rate equal to 622Mbps, 1.25 Gbps and 2.5Gbps and number of user K=150 for 2D ZCC/MD

4. CONCLUSION

Through this study a new code for two-dimensional hybrid spectral/spatial OCDMA code named 2D ZCC/MD has been proposed. The impact of PIIN noise, shot noise and thermal noise has been considered. Based on the numerical results as well as the comparing with other codes, the proposed code has a good performance and it can expand more active user with low bit error rate.

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