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Design And Simulation A New Code With Zero Cross-Correlation For SAC-OCDMA Networks

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Abstract: Design and simulation of new code family for the Spectral Amplitude Coding-Optical Code Division Multiple Access (SAC-OCDMA) networks is present. The new code family called Multi Diagonal (MD) code. The MD code family proposed for SAC-OCDMA applications due to, its advantages such as; the cross-correlation value still zeros in case of an increase the number of users for any weight value. Furthermore, the DCS code supports a large number of users and easy code construction. Based on the theoretical analysis MD code shows here to provide a much better performance compared to Modified Quadratic Congruence (MQC) code and Random Diagonal (RD) code. Proof–of-principle simulations of encoding of 10 users with 10 Gb/s data transmission at a BER of 3.5×10^{-14} have been successfully demonstrated together with the DIRECT detection scheme for 45 km fiber length without any amplification or side pumping.

Key words: Spectral Amplitude Coding-Optical Code Division Multiple Access (SAC-OCDMA), Multi Diagonal (MD) code, Modified Quadratic Congruence (MQC) code and Random Diagonal (RD) code.

INTRODUCTION

Last year, Spectral Amplitude Coding-Optical Code Division Multiple Access (SAC-OCDMA) networks, get attention due to it an ability to reduce the Multi Access Interference (MAI) by logging the unique code for each user (I.B. Djordjevic, 2004). Furthermore, MAI considered the main degradation factor, which reduced the system performance in SAC-OCDMA networks. Many codes have proposed for SAC-OCDMA networks such as; Optical Orthogonal code (OOC) (J.A. Salehi, 1989), prime code, Hadamard code (E.D.J. Smith, *et al*., 1998)], Modified Quadratic Congruence (MQC) code (Z. Wei, H. Ghafouri-Shiraz, 2002), Modified Frequency Hopping (MFH) code (Z. Wei, H. Ghafouri-Shiraz, 2002), Modified Double Weight (MDW) code (S.A. Aljunid, *et al*., 2004) and Random Diagonal (RD) code (Hillal Adnan Fadhil, 2009). These codes suffered from several limitations such as; the code length is too long (e.g., OOC, and prime code), the cross-correlation is increased with an increase the number of users (e.g., prime code, and Hadamard code), the code construction limited by the code parameter (e.g., MQC, and MFH codes), or with variable cross correlation (e.g., RD code).

To overcome these problems, we proposed Multi Diagonal (MD) code. The MD code designed based on a combination of diagonal matrixes. The new code have several advantages such as (1) zero cross-correlation code, which cancelled the MAI (multi access interference); (2) flexibility in choosing W, K parameters over other codes like MQC code ;(3) simple design;(4) large number of users in comparison to other codes like MQC or RD code ;(5) no overlapping of spectra for different users.

This paper, is organized as it follows. In section 2, Multi Diagonal (MD) code construction. In section 3, the performance analysis of the new proposed system is done, and finally, conclusions are given in section 4.

2. MD Code Construction:

The MD code is characterised by the following parameters (N, W, λc) where N is the code length (number of total chips), W is the code weight (chips that have a value of 1), and λ_c is the in-phase cross correlation.

The cross-correlation theorem states that cretin sets of complementary sequences have cross-correlation functions that sum to zero by using all pairwise permutations. Here, all cross-correlation function permutations are required in order that their sum be identically equal to zero. For example, if the rows and columns of a ($K \times$ N) matrix are orthogonal and all the columns except one sum to zero, then the sum of all cross-correlations between non-identical code word is zero.

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So if x_{ij} is an entry from X and y_{ij} is an entry from Y, then an entry from the product C=XY is given by $C_{ij} = \sum_{K=1}^{N} x_{iK}\, y_{Kj}$. For the code sequences $X = (x_1, x_2, x_3, ..., x_N)$ and $Y = (y_1, y_2, y_3, ..., y_N)$, the cross-correlation function can be represented by: $\lambda_c = \sum_{i=1}^{N} x_i y_i$.

When $\lambda_c = 0$, it is considered that the code possesses zero cross correlation properties. The matrix of the MD code consists of a $K \times N$ matrix functionally depending on the value of the number of users (K), and code weight (W). For MD code, the choice of weight value is free, but should be more than two.

A. MD Matrix Design

The following steps explain how the MD code is constructed.

Step 1:

Firstly, construct a sequence of diagonal matrices using the value of the weight (W) and number of subscribers (K). According to these values, the i, j_W will be set. Where K and W are positive integer numbers are defined by the number of rows in each matrix.

Where $j_W = 1,2,3,4,\cdots,W$ will represent the number of diagonal matrices.

Step 2:

Based on the next equations the MD sequences will be computed for each diagonal matrix.

$$S_{i,j_W} = \begin{cases} (i_n + 1 - i), & For\ \ j_W = \text{even number} \\ i, & For\ \ j_W = \text{odd number} \end{cases} \quad (1)$$

$$S_{i,1} = \begin{bmatrix} 1 \\ 2 \\ 3 \\ \vdots \\ K \end{bmatrix}, S_{i,2} = \begin{bmatrix} K \\ \vdots \\ 3 \\ 2 \\ 1 \end{bmatrix}, S_{i,3} = \begin{bmatrix} 1 \\ 2 \\ 3 \\ \vdots \\ K \end{bmatrix}, \dots, S_{i,W} = \begin{bmatrix} 1 \\ 2 \\ 3 \\ \vdots \\ K \end{bmatrix} \quad (2)$$

Any elements of the $S_{i,W}$ matrices represent the position of one in $T_{i,W}$ matrices with $K \times K$ dimensions.

where $T_{i,1} = [S_{i,1}]_{KxK}$, $T_{i,2} = [S_{i,2}]_{KxK}$ and $T_{i,W} = [S_{i,W}]_{KxK}$.

Therefore,

$$T_{i,1} = \begin{bmatrix} 1 & 0 & \cdots & 0 \\ 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 1 \end{bmatrix}_{KxK}, \dots, T_{i,W} = \begin{bmatrix} 1 & 0 & \cdots & 0 \\ 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 1 \end{bmatrix}_{KxK} \quad (3)$$

Step 3:

The total combination of diagonal matrices (3) represents the MD code as a matrix of power $K \times N$.

$$\text{MD} = [T_{i,1} \vdots T_{i,2} \vdots \cdots\cdots \vdots T_{i,W}]_{KxN} \quad (4)$$

$$\text{MD} = \begin{bmatrix} a_{1,1} & a_{1,2} & \cdots & a_{1,N} \\ a_{2,1} & a_{2,2} & \cdots & a_{2,N} \\ a_{3,1} & a_{3,2} & \cdots & a_{3,N} \\ \vdots & \vdots & \cdots & \vdots \\ a_{i_n,1} & a_{i_n,2} & \cdots & a_{i_n,N} \end{bmatrix} \quad (5)$$

From the above basic matrix (5), the rows determine the number of users (*K*). Notice that the association between code weight (*W*), code length (*N*) and number of subscribers (*K*) can be expressed as:

$$N = K \times W \tag{6}$$

For example, to generate a MD code family according to the previous steps, let's say *K*= 4 and *W*= 3.

Therefore, $i = 1,2,3,4$, $i_n + 1 = 5$ and $j_W = 1,2,3$

The diagonal matrices can be expressed as:

$$S_{i,1} = \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix}, S_{i,2} = \begin{bmatrix} 4 \\ 3 \\ 2 \\ 1 \end{bmatrix}, S_{i,3} = \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix} \tag{7}$$

The MD code sequence for each diagonal matrix is shown as:

$$T_{i,1} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}_{4\times4}, T_{i,2} = \begin{bmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}_{4\times4}, T_{i,3} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}_{4\times4} \tag{8}$$

The total MD code sequence will be:

$$MD = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}_{4\times12} \tag{9}$$

where *K*= 4, *N*= 12.

So the codeword for each user according to the above example would be:

$$\text{codeword} = \begin{cases} user1 \Rightarrow \lambda_1, \lambda_8, \lambda_9 \\ user2 \Rightarrow \lambda_2, \lambda_7, \lambda_{10} \\ user3 \Rightarrow \lambda_3, \lambda_6, \lambda_{11} \\ user4 \Rightarrow \lambda_4, \lambda_5, \lambda_{12} \end{cases}$$

The MD code design depicts that changing matrices element in the same diagonal part will result in a constant property of zero cross correlation, and it is constructed with zero cross correlation properties, which cancels the MAI. The MD code presents more flexibility in choosing the *W*, *K* parameters and with a simple design to supply a large number of users compared with other codes like MQC, RD codes. Furthermore, there are no overlapping chips for different users.

Table I show the code length (*N*), weight (*W*) and cross correlation value (λc) that is required for each code type to support only 30 users. MQC, RD codes show a shorter code length than that of MD code, and this will be discussed in further details in this paper. It will be shown that the transmission performance of MD code is significantly better than that of MQC or RD codes. This is achieved through mathematical analysis.

The MD code is constructed with ideal cross correlation property (λ_C = 0). The MD code presents more flexibility in choosing the *W*, *K* parameters and code length *N* with a simple design to supply a large number of users compared with other SAC-OCDMA codes.

Table I: SAC-OCDMA code Comparison for K=30.

Code	No. of users	Weight	Code length	Cross correlation (λ_C)
OOC	30	4	341	1
MDW	30	4	90	1
MQC	30	7	49	1
RD	30	4	35	Variable cross-correlation
MD	30	2	60	0

Finally, using the properties of MD code, the Signal to Noise Ratio (SNR) for MD code is derived mathematically as follows:

$$SNR = \left[\frac{\left(\frac{\Re P_{sr} W}{N} \right)^2}{\frac{eB\Re P_{sr} W}{N} + \frac{4K_b T_n B}{R_L}} \right] \tag{5}$$

Where the parameters that have been used in Eq. (5) are represented in Table II: 9456

Table II: System Parameters.

Symbol	Parameter
e	Electron charge
B	Electrical bandwidth
K_b	Boltzmann Constant
T_n	Receiver noise temperature
R_L	Receiver load resistor
$\Re$	Responsivity

The bit-error rate (BER) can be calculated using Gaussian approximation [5].

$$BER = 0.5erfc\left(\sqrt{\frac{SNR}{8}} \right). \tag{6}$$

B. MD code system description The MD code is design based on the direct detection technique, which is illustrated in Fig.1. However, in direct detection technique, there is only one single decoder and a single detector required for each user. Therefore, no subtraction or balance is required. This is achievable for the simple reason; the information can be adequately recovered from any of the chips that do not overlap with any other chips from other code sequences. Thus, the decoder will only need to filter the clean chips and be detecting by the photodiode.

3. Performance Analysis:

By using Eq. 6 the bit error rate (BER) of the MD code is tested mathematically with former code such as MQC code and RD code. Fig. 2 shows a variety of active users with BER, for MD, RD, and MQC codes. The calculated results were achieved under 311Mb/s, power spectral density of light source (Psr = -10 dBm), code weight (W=4), and number of active users K=160. While for RD and MQC codes, the weight code was W = 4 and W = 14 respectively. Fig. 2 shows that the performance of MD code is better than RD code and MQC code, even the comparison is made with high code value like MQC code or with same code weight such as RD code. Furthermore, the maximum acceptable BER of 10^{-9} is achieve by multi diagonal code with 90 active users, while 43 and 53 active users by MQC code and RD code respectively. This is better performance due to zero cross correlation property of MD code, which is reduced the effect of Multi Access interference (MAI) between the spectral light of other users.

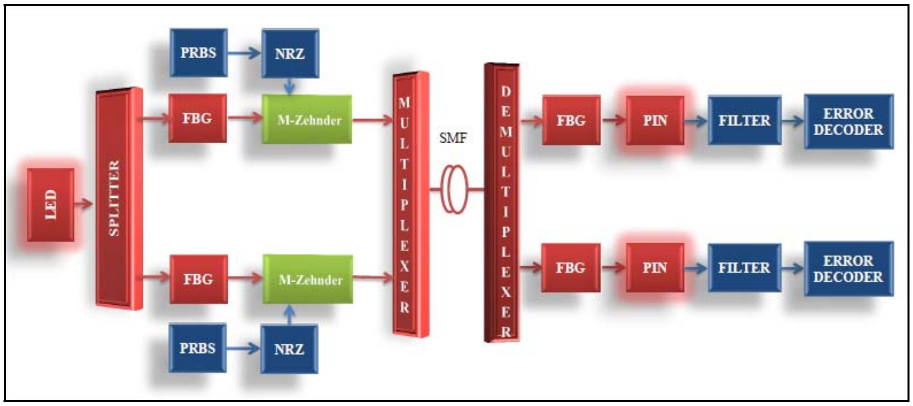

Fig. 1: Block diagram of an MD code system with direct detection technique.

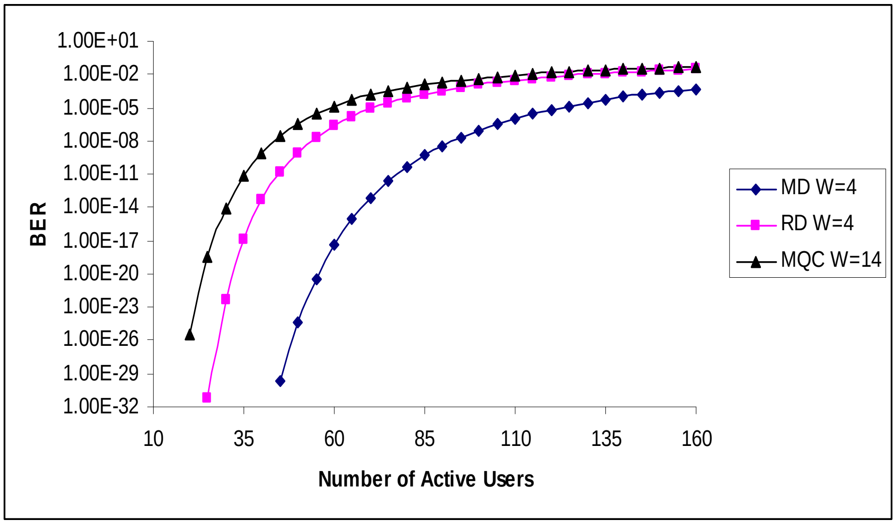

Fig. 2: BER versus the number of users for MD, RD and MQC codes.

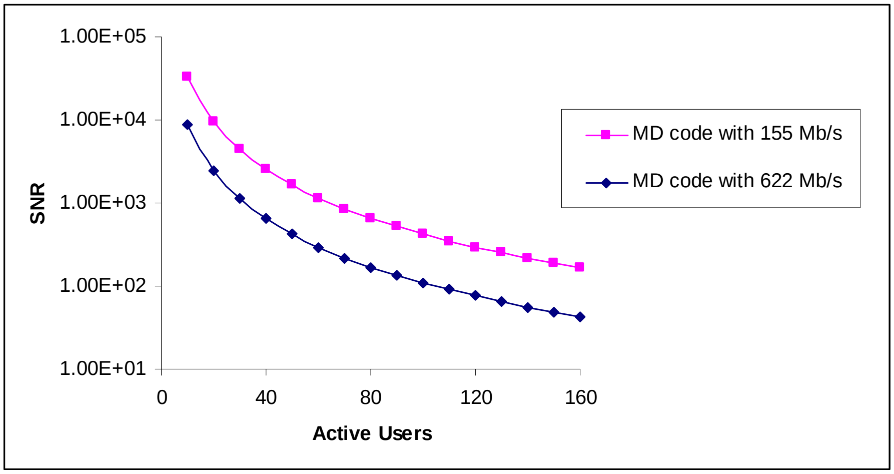

Fig. 3: SNR versus the number of users for different data rate employing MD codes.

Fig. 4 shows the system performance in terms of SNR for different data rate155 Mb/s and 622 Mb/s respectively, with a light source power P_{sr} = -10 dBm. Because of the non-existence of phase-induced intensity noise (PIIN) an increase in the number of simultaneous users hardly affects the system performance. Further, the scope of improvement in system performance is largely by increasing the effective power from each user at the receiver end. Moreover, it is also clear from the diagrams that an increase in a data rate causes degradation in the SNR.

The performance analysis of MD code is simulating by use the simulation software, Optisystem Version 9.0. The tests were carried out at a rate of 10 Gb/s with different fiber length such as 15, 30 and 45 km distance with the ITU-T G.652. standard single-mode optical fiber (SMF). The power of the light source is fixed at 0 dBm with 0.4 nm spectral width for each chip. All the attenuation α (i.e., 0.25 dB/km), dispersion (i.e., 18 ps/nm km), and nonlinear effects were activated and specified according to the typical industry values to simulate the real environment as close as possible.

The performance of the system is characterizing by referring to the BER and eye pattern. The eye pattern for MD code system as shown in Figs 4-6 below, clearly show that the MD code system gave a maximum BER (10^{-14}) as the fiber length is increase to be 45 km. The more the eye closes, the more difficult it is to differentiate between ones and zeros in the signal. The height of the eye opening at the specified sampling time shows the noise margin or immunity to noise. It should be noted that although the BER in Fig. 4 can go down to the value (10^{-80}) when the fiber length is 15 km, which is practically worthless; it does not contradict the objective of this study in comparing the performance of the system when fiber length more than 45 km.

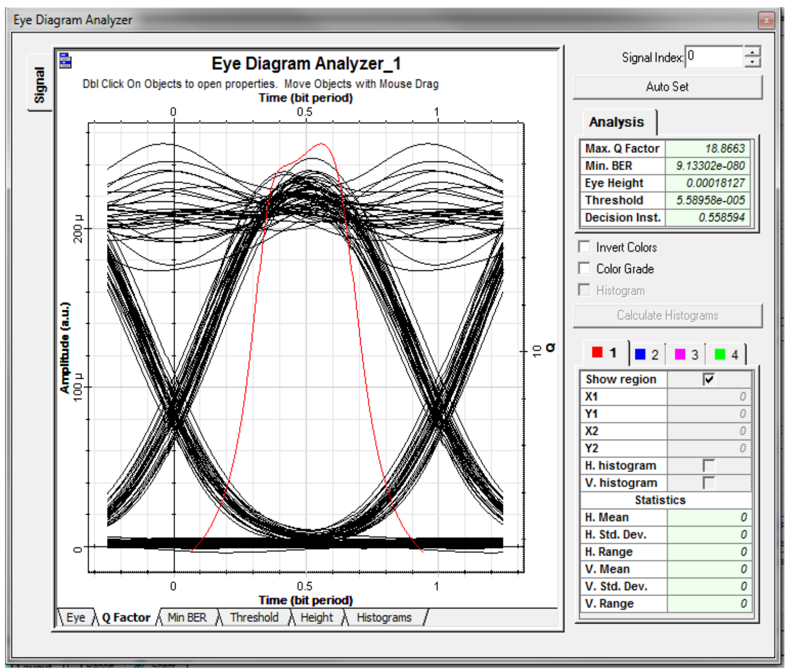

Fig. 4: Eye diagram of one of the MD code channels at 10 Gb/s for 15 km.

4. Conclusion:

A New code family with zero cross-correlation for SAC-OCDMA systems is successfully designed and simulated. The new code family, which called Multi Diagonal (MD) code, shows a better system performance in compared with former codes in same system complexity. The MD code have several advantages such as zero cross-correlation and easy code construction comparing with other SAC-OCDMA codes. Moreover, the code shows the flexibility in choosing the code parameter (e.g., number of users, the code weight and cross-correlation) and the number of users can increase for any integer number without the increase the code weight. However, in the absence of multi access interference, the system shows excellent performance with spectral amplitude coded asynchronous optical CDMA. Consequently, simplicity in code construction and flexibility in cross-correlation control has made this code a compelling candidate for future OCDMA applications.

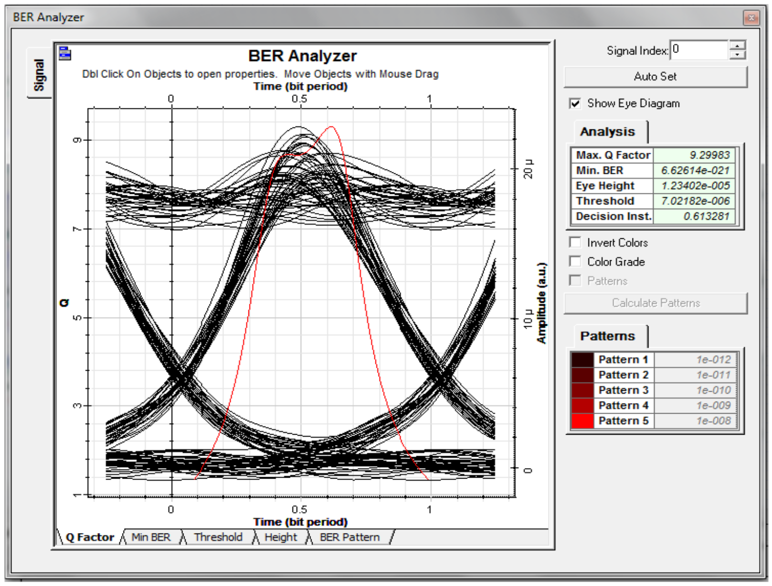

Fig. 5: Eye diagram of one of the MD code channels at 10 Gb/s for 30 km.

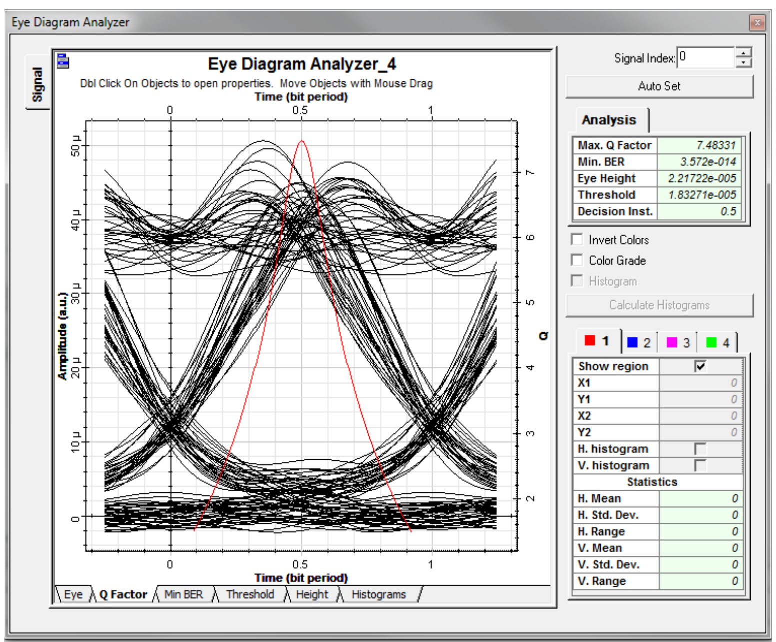

Fig. 6: Eye diagram of one of the MD code channels at 10 Gb/s for 45 km.

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