

Simulation of a SAC-OCDMA 10 User \times 15 Gb/s System Using MD Code

Morteza Motealleh*, Mohsen Maesoumi

Engineering Department, Azad University, Bushehr, 75131, Iran

Abstract Today, Optical Code Division Multiple Access (OCDMA) is applied as one of the most popular methods in multiple access systems. In this method, Multiple Access Interference (MAI) - which is one of the important factors of noise and interference in a system - is removed using Spectral Amplitude Coding (SAC). The present study presents a new SAC-OCDMA system using a 10-user MD code with data rate of 15 Gb/s in which transfer is made on a 30-km long single-mode fiber optic. Here, maximum bit error rate of 10^{-9} was achieved.

Keywords SAC-OCDMA, MD code, Optisystem

1. Introduction

OCDMA systems are impaired due to different noises such as beat noise, thermal noise, dark current, MAI caused by other users [2, 1]. MAI is considered as the most important noise [3]. SAC-OCDMA system offered a favorable solution that mitigates the effect of MAI using optimal codes with a fixed in-phase cross-correlation [7-4]. To remove MAI and facilitate synchronization, sequence of different transmitters needs low cross-correlation and high self-correlation [7]. In practice, sequences have little sparse to satisfy this condition [8].

In SAC-OCDMA method, frequency content of a signal is encrypted by selective blocking. Alternatively, it transfers them according to a code signature. SAC-OCDMA is a suitable candidate for an access environment in which cost is considered as one of the important factors [4, 1].

This paper presents a new SAC-OCDMA system using an MD code corrected by 10×15 Gb/s, while maximum bit error rate of 10^{-9} was achieved among the users. Simulation was performed by Optisystem Ver. 7.

Contents of this article are as follows: Section 2 discusses MD code structure and the way to create its matrix. Section 3 explains numeric analysis of MD code, compares numeric analysis of different codes, and presents the results. Section 4 offers the results obtained from simulation of the new design and related diagrams. Conclusion is offered in section 5.

2. Structure of MD Code

An MD code is designed based on a combination of diagonal matrices. This code has following advantages [9]:

- It has zero cross-correlation that removes MAI.
- It shows further flexibility to select weight parameters and number of rows of a matrix as compared with other codes such as MQC.
- It is easy to design.
- It is able to support many users with high rate of data.
- The code is in a way that overlapping does not occur for spectral characteristic of users.

An MD code is specified by N , W , and λ_c parameters where N is code length (total number of chips), W is code weight (number of chips with a unit value), and λ_c is in-phase cross-correlation.

To create an MD code, we show unit matrix as:

$$I_1 = [1], I_2 = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}, \dots, I_N = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & \ddots & 0 \\ 0 & 0 & \dots & 1 \end{bmatrix}$$

I_N can be shown as $I_N = \text{diag}(1, 1, \dots, 1)$. The offered orthogonal matrix is a square matrix with real values whose rows and columns include orthogonal unit vectors. In other words, matrix A will be orthogonal if its transpose is equal to its reverse matrix, i.e.

Now, cross-correlation theory expresses that a specified set of complementary sequences has a cross-correlation function that their total number - using permutations of all pairs - is zero. Here, all the permutations of cross-correlation function are required, as their total is exactly equal to zero. For instance, if rows and columns of a $K \times N$ matrix are orthogonal and all the columns - except one of them - have zero-sum, total of all the cross-correlation among words of

* Corresponding author:
m.motealleh2014@gmail.com (Morteza Motealleh)
Published online at <http://journal.sapub.org/optics>
Copyright © 2014 Scientific & Academic Publishing. All Rights Reserved

incoherent code will be zero [3].

Therefore, if x_{ii} is an element of X and y_{ii} is an element of Y , an element of $C=XY$ matrix will be achieved by

$$C_{ij} = \sum_{K=1}^N x_{iK} y_{Kj}$$

equation. A cross-correlation function with

$$\lambda_c = \sum_{i=1}^N x_i y_i$$

equation is obtained for $X=(X_1, X_2, \dots, X_N)$ and $Y=(Y_1, Y_2, \dots, Y_N)$ sequence code. Therefore, if $\lambda_c = 0$, the code with cross-correlation feature is zero. Matrix of MD code shows a $K \times N$ matrix with functional dependency on number of K rows and weight of W code. Though MD code should have a value higher than one, selection of weight is free for this code. MD code is created as below:

Step 1)

First, we create sequence of a diagonal matrix with specific values of weight (W) and number of rows (K). According to these values, we have i and j_w sets. Here, K and W are positive figures. Therefore, $i=1, 2, 3, 4, \dots, i_n=K$ is number of rows in each matrix and $j_w=1, 2, 3, 4, \dots, W$ shows number of diagonal matrices.

Step 2)

MD sequence for each matrix is calculated by relation (1):

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

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

$$S_{i,j_w} = \begin{cases} (i_n + 1 - i), & \text{for } j_w = \text{even} \\ i & \text{for } j_w = \text{odd} \end{cases}$$

It is clear that

$$T_{i,1} = [S_{i,1}]_{K \times K}, T_{i,2} = [S_{i,2}]_{K \times K}, \dots, T_{i,W} = [S_{i,W}]_{K \times K}$$

Therefore

$$T_{i,1} = \begin{bmatrix} 1 & 0 & \dots & 0 \\ 0 & 1 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & 1 \end{bmatrix}_{K \times K}, T_{i,2} = \begin{bmatrix} 0 & \dots & 0 & 1 \\ 0 & \dots & 1 & 0 \\ \vdots & \ddots & \vdots & \vdots \\ 1 & \dots & 0 & 0 \end{bmatrix}_{K \times K}, \dots (2)$$

Step 3)

Combination of all the diagonal matrices in equation (2) provides MD code.

$$MD = [T_{i,1} \quad T_{i,2} \quad \dots \quad T_{i,W}]_{K \times K} \quad (3)$$

$$MD = \begin{bmatrix} a_{1,1} & a_{1,2} & \dots & a_{1,N} \\ a_{2,1} & a_{2,2} & \dots & a_{2,N} \\ a_{3,1} & a_{3,2} & \dots & a_{3,N} \\ \vdots & \vdots & \ddots & \vdots \\ a_{i_n,1} & a_{i_n,2} & \dots & a_{i_n,N} \end{bmatrix}_{K \times K}$$

In the base matrix given in equation (3), the rows specify number of users. Note that the relationship between code weight, code length, and number of subcarriers is specified by.

$$N=K \times W \quad (4)$$

For instance, suppose $K=5$ and $W=2$. Therefore, $i=1,2,3,4,5$ and $i_n+1=6$ and $j_w=1,2,3,4$. Diagonal matrix is expressed as

$$S_{i,1} = \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{bmatrix}, S_{i,2} = \begin{bmatrix} 5 \\ 4 \\ 3 \\ 2 \\ 1 \end{bmatrix}, S_{i,3} = \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{bmatrix}, S_{i,4} = \begin{bmatrix} 5 \\ 4 \\ 3 \\ 2 \\ 1 \end{bmatrix}$$

Consequently, sequence of MD code for each diagonal matrix is defined as

$$T_{i,1} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}_{5 \times 5}, T_{i,2} = \begin{bmatrix} 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \end{bmatrix}_{5 \times 5} \quad (5)$$

Finally, the MD achieved from the equation of sequence of MD code is as (6)

$$MD = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 \end{bmatrix}_{5 \times 10} \quad (6)$$

where $K=5$ and $N=10$.

3. Numerical Analysis

Systems efficiency is specified by bit error rate. In this mode, Gaussian approximation is applied to calculate bit

error rate that thermal noise (σ_{th}) and beat noise (σ_{sh}) were considered. As MD code has zero correlation feature, overlapping does not exist in different range of users. Therefore, the effect of relative intensity noise of phase is not considered.

Variance of the optical detector is expressed as relation (7).

$$\sigma^2 = \sigma_{sh} + \sigma_{th} = 2eBI + \frac{4K_b T_n B}{R_L} \quad (7)$$

e is electron load, I is mean of optic current, B is electric bandwidth in receiver section, K_b is Boltzmann constant, T_n is receiver noise temperature, and R_L is receiver load resistance.

Suppose that $C_k(i)$ is the i_{th} member of k_{th} sequence of matrix of MD code, according to the properties of MD code and using direct detection method, we can write

$$\sum_{i=1}^N c_k(i) c_1(i) = \begin{cases} W & k = 1 \\ 0 & k \neq 1 \end{cases}$$

N is length of MD code. Density of spectrum power of the received optic signal is as relation (8).

$$G(v) = \frac{P_{sr}}{dv} \sum_{k=1}^K d_k \sum_{i=1}^N c_k(i) c_1(i) \prod(i) \quad (8)$$

K is total number of users, d_k is data bit of k_{th} user with one and zero values, P_{sr} is effective power of bandwidth light source in a receiver by bandwidth of Δv and

$$\prod(i) = u \left[v - v_0 - \frac{dv}{2N} (-N + 2i) \right] - u \left[v - v_0 - \frac{dv}{2N} (-N + 2i + 2) \right]$$

where

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

For calculating $G(v)$ integral, see density of the spectrum shown in Figure 1, where $A(i)$ is amplitude of spectrum signal with dv/N width. Using relation (8), integral of power density spectrum of optic detector of i_{th} receiver over a period is written as follows:

$$\int_0^\infty G(v) dv = \int_0^\infty \left[\frac{P_{sr}}{dv} \sum_{k=1}^K d_k \sum_{i=1}^N c_k(i) c_1(i) \prod(i) \right] dv \quad (9)$$

A simple form of equation (9) is

$$\int_0^\infty G(v) dv = \frac{P_{sr}}{dv} \int_0^\infty \left[\sum_{k=1}^K d_k \cdot W \cdot \frac{dv}{N} \right] dv \quad (10)$$

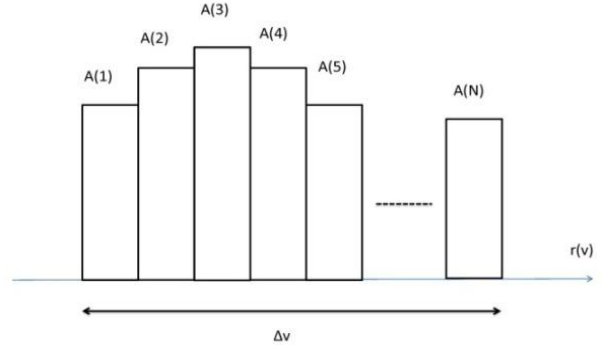


Figure 1. Density of power of the received signal spectrum $r(v)$

When all users send a bit, then

$$\sum_{k=1}^K d_k = d_1 + d_2 + d_3 + \dots + d_K = W$$

As a result

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

Optic flow (I) is as relation (11)

$$I = \mathcal{R} \int_0^\infty G(v) dv \quad (11)$$

where

$$\mathcal{R} = \frac{e\eta}{h\lambda}$$

Moreover, η is efficiency of optical detector quantum, h is Planck's constant, and λ is central wavelength.

Relation (11) can be expressed as relation (12).

$$I = \mathcal{R} \int_0^\infty G(v) dv = \frac{\mathcal{R} P_{sr} W^2}{N} \quad (12)$$

Following relation is obtained by putting relation (12) in relation (7):

$$\sigma^2 = \frac{2eB\mathcal{R}P_{sr}W^2}{N} + \frac{4K_b T_n B}{R_L} \quad (13)$$

As probability of transmitting bit 1 at any time for every user is 0.5, relation (13) is changed as

$$\sigma^2 = \frac{eB\mathcal{R}P_{sr}W^2}{N} + \frac{4K_b T_n B}{R_L}$$

As a result, signal to noise ratio is obtained as relation (14)

$$SNR = \frac{I^2}{\sigma^2} = \frac{\left(\frac{\mathcal{R} P_{sr} W^2}{N} \right)^2}{\frac{eB\mathcal{R}P_{sr}W^2}{N} + \frac{4K_b T_n B}{R_L}} \quad (14)$$

Using Gaussian approximation, probability of bit error is obtained as relation (15).

$$\text{BER} = \frac{1}{2} \operatorname{erfc} \left(\sqrt{\frac{\text{SNR}}{8}} \right) \quad (15)$$

In order to be confident of a favorable comparison between system efficiency and MD code, similar parameters of recent works were used here. Table 1 shows the parameters used for calculating MD code and other codes of SAC-OCDMA.

Table 1. General parameters used in numerical analysis

| Parameter | Symbol | Quantity | Unit |
|------------------------------|-------------|----------|------|
| Effective Power of Broadband | P_{sr} | -5 | dBm |
| Electric Bandwidth | B | 311 | MHz |
| Central Wavelength | λ_0 | 1550 | Nm |
| Data Bit Rate | R_b | 15 | Gb/s |
| Receiver Noise Temperature | T_n | 300 | K |
| Receiver Load Resistance | R_L | 1030 | Ohm |

Figure 2 shows bit error rate in terms of number of active users for the different codes used in SACO CDMA method. Here, data transfer rate for each user and power of effective broadband are 622 Mb/sec and 10 dBm, respectively. It is observed that efficiency of MD code is better than other codes. Even weights of other codes are bigger than weight of MD code. Maximum acceptable bit error rate of 10^{-9} was

achieved for MD code with 92 active users (comparing with 43 active users for MQC, 59 users for RD, 27 users for MFHⁱ, 38 users for KS, and 39 users for EDW). This result is due to the fact that MD code has zero cross-correlation feature, but other codes have variable cross-correlation between zero and one. On the other hand, other codes have further code length as compared with MD codes. As Figure 2 shows, bit error rates for EDW, MD, KS, RD, MFH, and MQC were calculated for weights of 3, 4, 4, 5, 12 and 14, respectively.

4. Design Simulation

Simulation of design was carried out using Optisystem ver.7.

Figure 3 shows diagram of the proposed design for 2 users. In this design, laser light source was used in the transmitter section and number of lasers is specified with respect to the code weight. This diagram uses MD code with weight 4. Then the electric data of each user is modulated by Mach-Zehnder modulator on a light source. Finally, before transmitting signal by the signal receiver, all users are collected by a synthesizer and transmitted through the channel. Single-mode fiber optic with attenuation coefficient of 0.2 db/km and dispersion of 16.75 db/nm/km was used in channel section. Moreover, non-linearity effects of fiber were considered. In the receiver section, the signal received from FBG is sent out uniformly. Finally, the received signal is sent out through an optic detector for detecting and converting light signal to electric signal. The detector creates a current in the detector output in proportion to the density of the received signal. Finally, to remove the remaining noise on the detected signal, the signal is sent out through a low-pass filter.

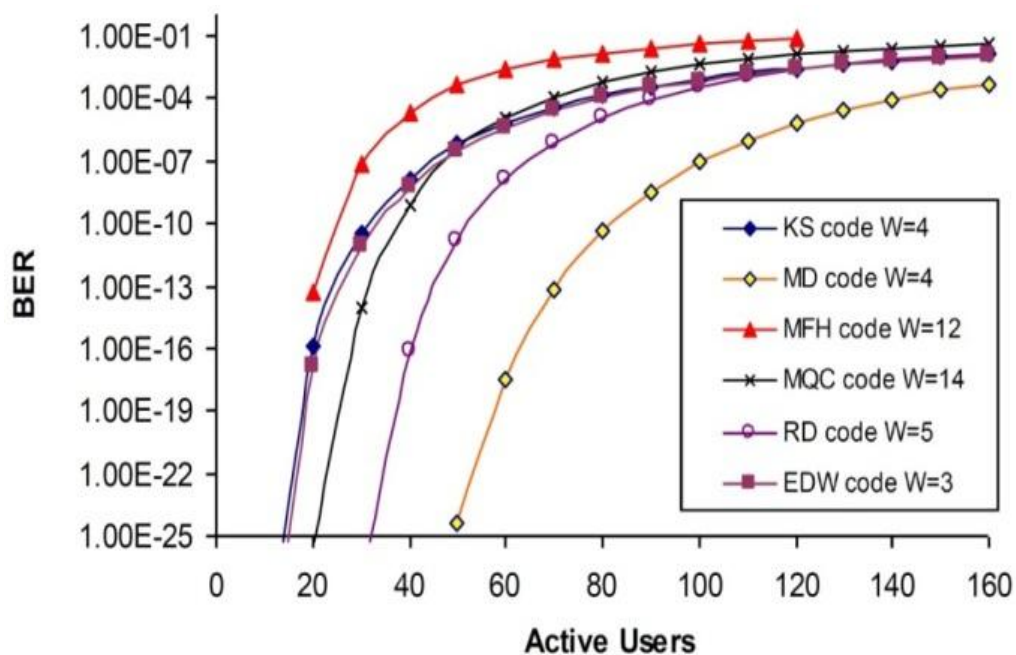


Figure 2. Bit error rate in terms of number of users for the different codes used in SAC-OCDMA for a 10-dBm power of light source [11]

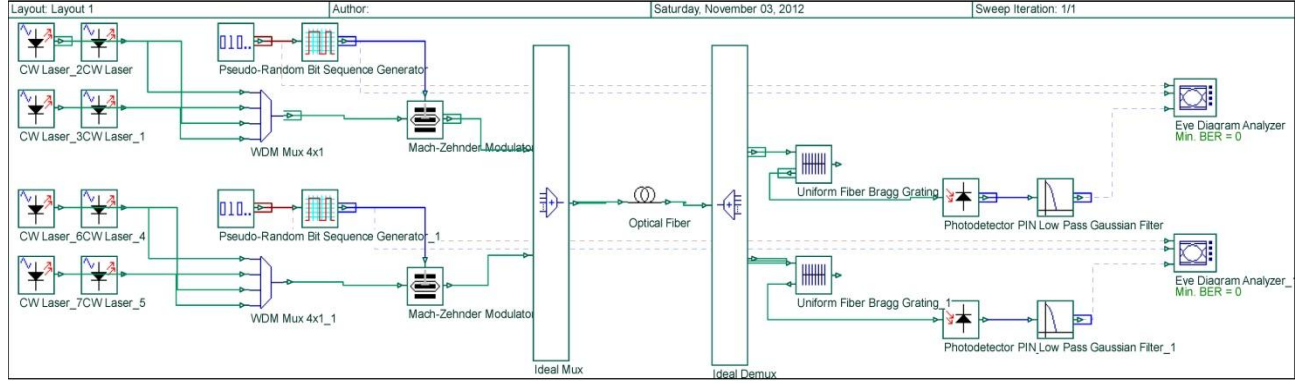


Figure 3. Proposed design for SAC-OCDMA system

Figures 4 and 5 show eye diagrams for user 1 and user 10, respectively that was obtained for a 30-km long fiber and data transfer rate of 15 Gb/s. In this mode, maximum data transfer rate among users was obtained as 10^{-9} . As is clear from figures 4 and 5, the signal quality is good and it can be seen that the design is well done.

In the figure 6, bit error rate graph in terms of data rate is presented for various designed. As it is clear in the figure, the structure proposed with MD code, has better performance than schemes are presented in an equal weights code, number of users and transmitter power.

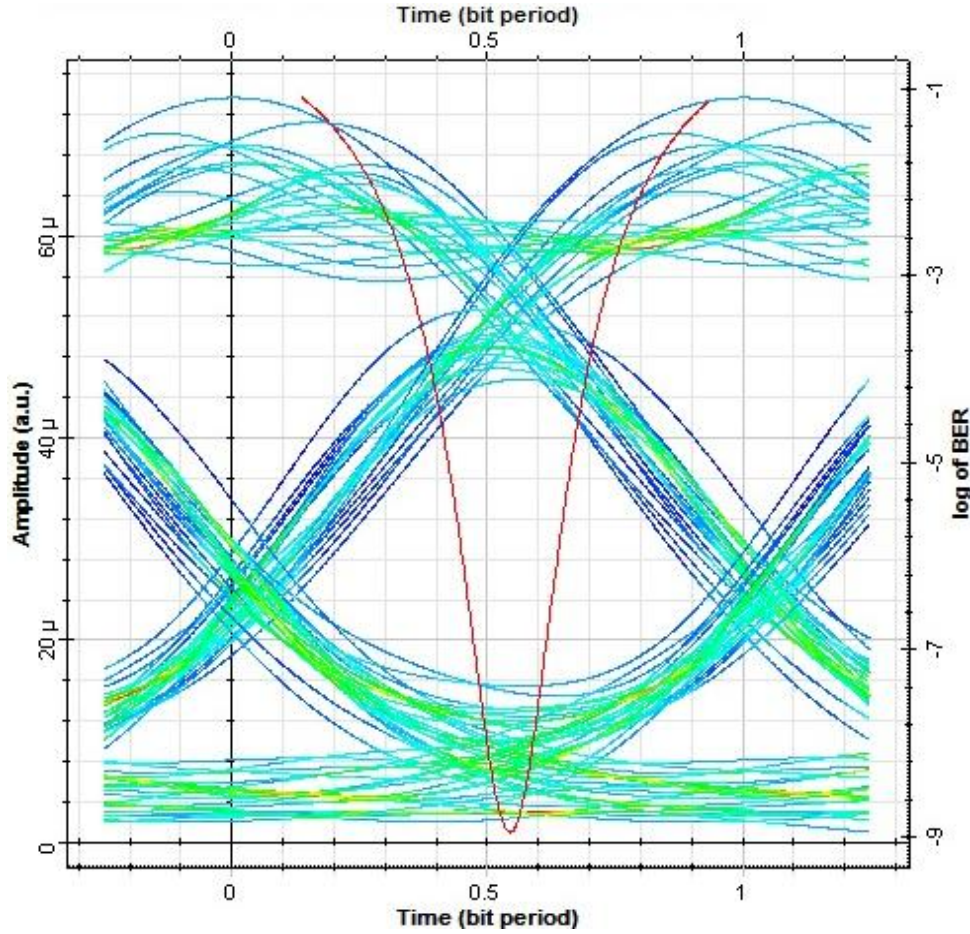


Figure 4. Eye diagram of user 1

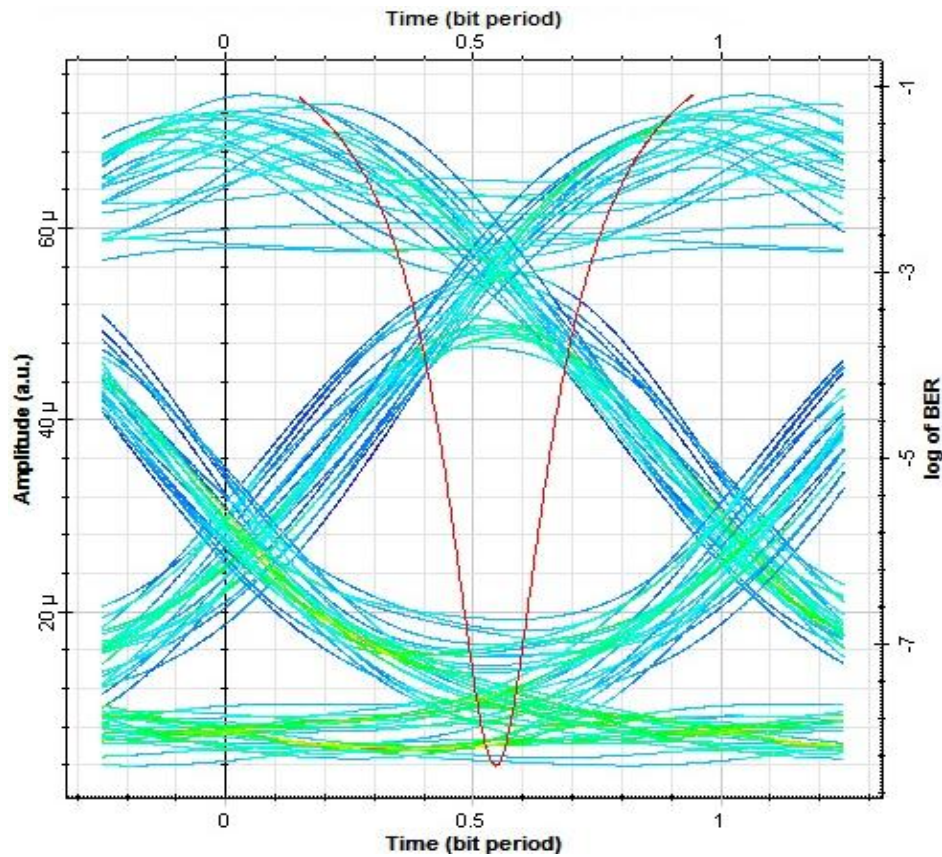


Figure 5. Eye diagram of user 10

It can be concluded that MD code compared with KS, MFH, MQC, RD, EDW codes has a suitable performance for optical system and it also has a good flexibility to choose the parameters of the code, and the other side supports of more users. Using the scheme presented in Section 4, the optical system can be achieved with appropriate parameters.

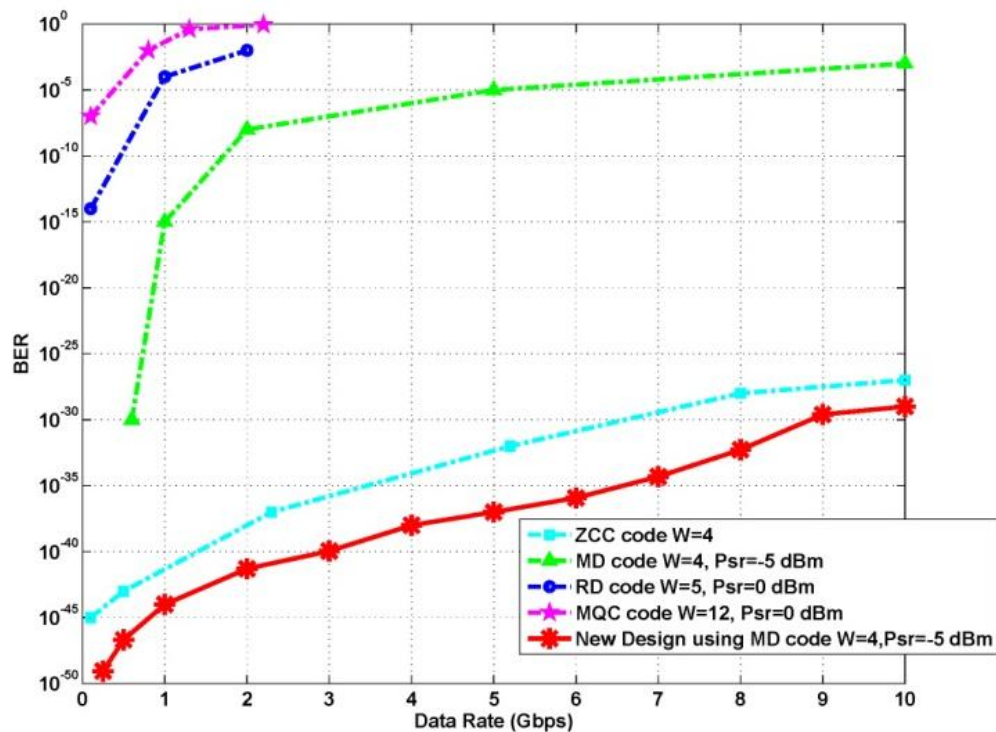


Figure 6. Bit error rate in terms of data rate for the different codes used in SAC-OCMA

5. Conclusions

This article presented a new SAC-OCDMA system. In this design, the effect of beat noise and thermal noise was considered as 10^{-22} watt/Hz and error rate of 10^{-9} was achieved for 10 users. Due to the zero cross-correlation of MD code, the encoder and decoder applied in the design are simple as far as complexity is concerned. Direct detection was used due to lack of overlapping. The designed system has the best transfer rate of 15 Gb/s for each user that achieved along a 30-km long fiber.

REFERENCES

- [1] M. S. Anuar, S. A. Aljunid, N. Saad, and S. Hamzah, "New design of spectral amplitude coding in OCDMA with zero cross-correlation," *Optics Communications*, vol. 282, pp. 2659-2664, 2009.
- [2] B. Djordjevic, B. Vasic, and J. Rorison, "Multi-weight unipolar codes for multimedia spectral-amplitude-coding optical CDMA systems," *Communications Letters, IEEE*, vol. 8, pp. 259-261, 2004.
- [3] H. A. Fadhil, S. A. Aljunid, and R. Ahmad, "Performance of random diagonal code for OCDMA systems using new spectral direct detection technique," *Optical Fiber Technology*, vol. 15, pp. 283-289, 2009.
- [4] M. Kavehrad and D. Zaccarin, "Optical code-division-multiplexed systems based on spectral encoding of noncoherent sources," *Lightwave Technology, Journal of*, vol. 13, pp. 534-545, 1995.
- [5] J. A. Salehi, "Code division multiple-access techniques in optical fiber networks. I. Fundamental principles," *Communications, IEEE Transactions on*, vol. 37, pp. 824-833, 1989.
- [6] E. D. Smith, R. J. Blaikie, and D. P. Taylor, "Performance enhancement of spectral-amplitude-coding optical CDMA using pulse-position modulation," *Communications, IEEE Transactions on*, vol. 46, pp. 1176-1185, 1998.
- [7] Stok and E. H. Sargent, "Lighting the local area: Optical code-division multiple access and quality of service provisioning," *Network, IEEE*, vol. 14, pp. 42-46, 2000.
- [8] Z. Wei and H. Ghafouri-Shiraz, "Codes for spectral-amplitude-coding optical CDMA systems," *Lightwave Technology, Journal of*, vol. 20, pp. 1284-1291, 2002.
- [9] Z. Wei and H. Ghafouri-Shiraz, "Unipolar codes with ideal in-phase cross-correlation for spectral amplitude-coding optical CDMA systems," *Communications, IEEE Transactions on*, vol. 50, pp. 1209-1212, 2002.
- [10] A.M. Safar, S.A. Aljunid, A. Razif, A.J. Abdullah, J.M. Nordin, M.N. Mohamad Saad, —Enhancement of Zero Cross Correlation Code for Optical CDMA Network System || , *International Conference on Communications and Information Technology*, 2012.
- [11] T. H. Abd, S. Aljunid, H. A. Fadhil, I. F. Radhi, R. Ahmad, and M. Rashid, "Performance improvement of hybrid SCM SAC-OCDMA networks using multi-diagonal ccode," *Sci. Res. Essays*, vol. 7, pp. 1262-1272, 2012.

ⁱ Modified Frequency-Hopping