International Journal on Electrical Engineering and Informatics - Volume 9, Number 4, December 2017

A New MIHP Code Using Direct Detection for SAC-OCDMA System

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Abstract: Several codes have been propounded to be implemented in Optical Code Division Multiple Access (OCDMA) using spectral amplitude coding (SAC). In this work, we suggest a new code structure for SAC-OCDMA system, we demonstrate theoretically and practically the good quality of the proposed system. The new code is called multi-identity high-power code (MIHP). This code with its architecture and facility of construction provides good performance with regard to BER. Without any constraint, MIHP codes can be adjusted to any number of users and weight. In this architecture the use of direct detection which reduces significantly the MAI. The result shows that the proposed code in SAC OCDMA system provides better performance and gave a BER equal to 8.70886e-17, the system using the suggested code can reach a length of 115 km for a bit error rate of 10^{-9} without using any amplifier.

Keywords: MIHP code; SAC-OCDMA; direct detection; eye diagram.

1. Introduction

Code Division Multiple Access for optical communication (OCDMA), as in radio communication, is a multiplexing technique that is becoming increasingly desirable in the field of optical communications and is widely used. The different users share the same optical channel and each in the network has a specific code that allows simultaneous and asynchronous access to the network avoiding the interference resulting from the transmission of other users at the same time (MAI), which limit the system BER error rate. [1-2-3].

In all types of optical multiple access code division systems (OCDMA), the spectral encoding systems (SAC) have received more attention in recent years as the multiuser interference can be eliminated when a code cross-correlation is used in stationary phase [4]. The elimination of MAI occurs at the receiver which is a function of the detection technique used. Complementary detection technique, subtraction detection technique and direct detection technique are the most widely used detection techniques in SAC OCDMA systems [5].

To establish the SAC-OCDMA, we must solve the problem of the orthogonal code. Many researchers have proposed several codes such as Code premium, OOC code…etc.

H. A. Fadhil et al [6] suggest a new code called Random Diagonal (RD) which is constructed by dividing the code into two parts data segment, with $\lambda = 0$, and code segment for the SAC-OCDMA using direct detection technique, this technique reduce a kind of noise called PIIN. T. H Abd et al [7] have proposed the Multi-Diagonal (MD) code with zero cross-correlation which means that PIIN is suppressed.

In this article, we are interested in the proposed multi-identity high power codes (MIHP). In Section 2 we will show how these codes have been developed theoretically and we will discuss their properties. Analyze and interpret the performance of the system is presented in Section 3. Finally, a conclusion of this work is shown in Section 4.

2. MIHP Code Construction

The new proposed MIHP code is represented in a matrix with a size where (row) represents the number of users and the (column) represents the code length.

Received: August 11st, 2017. Accepted: December 23rd, 2017
DOI: 10.15676/ijeei.2017.9.4.14

- $nu \longrightarrow$ number of users
- $k \longrightarrow$ the k^{th} user
- $w \longrightarrow$ the weight of the code
- $i \longrightarrow$ number of the diagonals

A. The Matrix Construction

On a combination of two matrices, the proposed code is designed as follows:

- Multi-identity matrix
- All-Ones matrix.

A.1 Multi-identity matrix

First, we define the number of the diagonal which is equal to i.We set I_N the identity matrix where N is the number of users.

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

The number of "1" in each row is equal to '1' and the cross correlation $\lambda = \sum_{i=1}^{N} x_i y_i$ equal to '0'.

This property, which reduces the PIIN in SAC OCDMA system, is represented in a matrix called multi- identity matrix (MI), of a size N × N where N is the number of users. Take the example of an MI matrix with a number of users $nu = 4$ and $i = 4$.

The matrix MI is created the as follows:

$$MI = [I_{4,i}] = [I_{4,1}, I_{4,2}, I_{4,3}, I_{4,4}] \tag{2}$$

$$MI = \begin{bmatrix} 1\,0\,0\,0\,1\,0\,0\,0\,1\,0\,0\,0\;1\,0\,0\,0 \\ 0\,1\,0\,0\,0\,1\,0\,0\,0\,1\,0\,0\;0\,1\,0\,0 \\ 0\,0\,1\,0\,0\,0\,1\,0\;0\,0\,1\,0\;0\,0\,1\,0 \\ 0\,0\,0\,1\,0\,0\,0\,1\;0\,0\,0\,1\;0\,0\,0\,1 \end{bmatrix} \tag{3}$$

Note that this matrix keeps the property zero cross correlation between users (rows) [7-8].

A.2 All-ones matrix

The construction of the second part is made with a very simple way: a matrix which contains '1' must be created, where the number of the rows (users) is equal to N and the columns is equal to w-i.

Example if $w = 4$ and $i = 2$, the number of '1' added is equal to 2.

So for a number of users $nu = 4$, a weight $w = 4$ and $i = 2$ the generated matrix is presented as follows:

$$\mathrm{Ones} = \begin{bmatrix} 1\,1 \\ 1\,1 \\ 1\,1 \\ 1\,1 \end{bmatrix} \tag{4}$$

From bases mentioned above (3) and (5), the matrices representing our code of size $(nu \times l)$ is determined by the number of users (nu) and the length of the code (l).

The relation between nu, l and w can be expressed as follows:

$$l = (nu \times i) + (w - i) \tag{5}$$

And the generated code can be constructed by combining the two matrices MI and all-Ones as shown below:

$$\mathrm{MIHP} = [\mathrm{MD}, \mathrm{Ones}] \tag{6}$$

As an example, we can generate the MIHP code who is used in the simulation with a number of users nu $= 3$, w $= 3$ and i $= 1$ which implies that the code length l= 5.

$$\mathrm{MIHP} = \begin{bmatrix} 1 & 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 & 1 \\ 0 & 0 & 1 & 1 & 1 \end{bmatrix} \tag{7}$$

Referring to (7), the wavelength assignment to the MIHP code for each user (Figure 1) is as follows:

$$\text{codeword} = \begin{cases} \text{user1} = \lambda_1, \lambda_4, \lambda_5 \\ \text{user2} = \lambda_2, \lambda_4, \lambda_5 \\ \text{user3} = \lambda_3, \lambda_4, \lambda_5 \end{cases} \tag{8}$$

Greater flexibility in the choice of parameters k and w is one of the property during construction of MIHP code, and which leads to a simple design that provides a large number of users.

A very short length of code limits the flexibility addressing codes, while the long code length is regarded as a disadvantage in the implementation. the key point of the proposed MIHP code is that it offers better performance than the other proposed codes for OCDMA systems such as optical orthogonal code (OOC), the modified frequency hopping (MFH) codes and Hadamard code…., in terms of the length of the code for the same number of users un = 30, as indicated in Table 1.

Table 1. Comparison between of the different codes lengths

Code	N° of users K	Weight W	Code length l
OOC	30	4	364
MD	30	3	90
MDW	30	4	90
MIHP	30	3	32

3. System Performance Analysis

Figure 1 illustrates the structure of SAC OCDMA system encoder and decoder network with three users and five chips for each user. The matrix used for encoding is as follows:

$$Z = \begin{bmatrix} 1 & 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 & 1 \\ 0 & 0 & 1 & 1 & 1 \end{bmatrix} = \begin{bmatrix} \lambda_1 0\ 0\ \lambda_4 \lambda_5 \\ 0\ \lambda_2 0\ \lambda_4 \lambda_5 \\ 0\ 0\ \lambda_3\ \lambda_4 \lambda_5 \end{bmatrix}$$

At the reception, the data of all users will be gathered, so it is necessary to use the code of each user to restore the desired data. Removing MAI and PIIN is reached by choosing only the non-overlapping spectrum of the desired code sequence.

In the example studied, λ_1 is the chip used for decoding the first user, because when we observe the matrix, λ_4 and λ_5 are common between the first user and the other users. In the same way, the chips are defined for the second and the third user.

Therefore, the choice of the direct detection technique, to recover the desired data, led MIHP code to behave similarly as a code with zero cross-correlation.

A. Gaussian Approach Analysis

Three quality criteria are used to measure the performance of the SAC-OCDMA system [9]:

- Bit error rate

- The Q factor
- The eye diagram

To simplify system analysis, Gaussian approximation is used for calculation of BER [8-10].

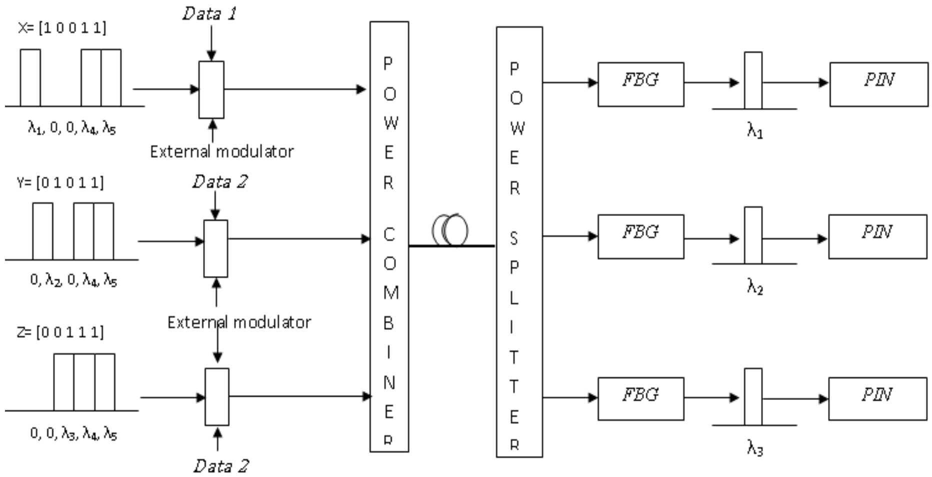

Figure 1. The proposed SAC-OCDMA system using MIHP code

Referring to the property of MIHP code only thermal noise and shot noise were taken into account for analyzing bit error rate (BER), the setup of the proposed MIHP system using spectral direct detection technique with three users exploits fiber Bragg-grating (FBG) is shown in Figure 1.

The average signal to noise ratio (SNR) according to the properties of MIHP code is calculated as follows [11]:

$$\mathrm{SNR} = \frac{\left(\frac{\mathrm{RP_{sr}w}}{\mathrm{L}}\right)^2}{\frac{\mathrm{eBRP_{sr}w}}{\mathrm{L}} + \frac{4\mathrm{K_B T_n B}}{\mathrm{R_L}}} \tag{9}$$

BER equation can be calculated by using Gaussian approximation as follows:

$$\mathrm{BER} = \frac{1}{2}\mathrm{erfc}\sqrt{\frac{\mathrm{SNR}}{8}} \tag{10}$$

B. Mathematical Analysis

The performance of MIHP code system has been compared mathematically with the recent codes, such as Multi-Diagonal (MD) and ZCC [11].

Figure 2 shows that the SAC OCDMA system using MIHP code present better quality compared to the other SAC OCDMA codes, for the effective receiver power Psr = -10 dBm. This is due to the reduced length of the proposed code MIHP while maintaining the same weight (w) as mentioned in section 2 and section 3, and also the fact of using the Direct Detection which makes the behavior of the MIHP code similar to a ZCC code.

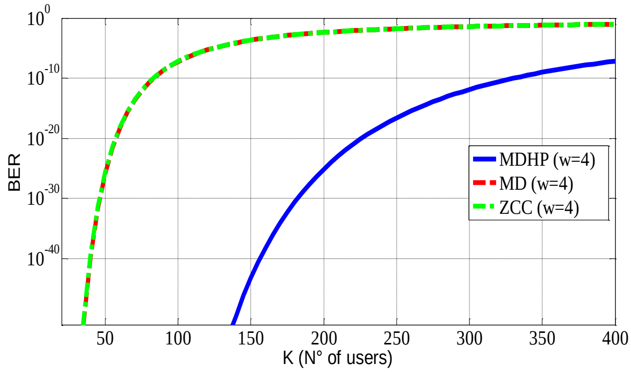

Figure 2. BER versus the number of active users

4. Simulation result

In order to enrich our work, a block diagram of SAC OCDMA system for four users using MIHP code is simulated using the Opti system software.

In coding part, Figure 3, optical demultiplexers and multiplexers were used to build the proposed code. The principle of this technique is very simple. The broadband spectrum of the LED is divided into several wavelengths, of the same width, with the aid of an optical demultiplexer. From the outputs of the demultiplexer, each user can collect the wavelengths (which represent the number of inputs of the optical multiplexer) that constitute his spectral signature using a multiplexer as shown in Figure 4.

At the reception, the data of all users will be gathered, so it is necessary to use the code of each user to restore the desired data.

As illustrated in Figure 5 the proposed system, in detection part, used a fiber Bragg grating (FBG) which is used to decode the desired code at the first matrix called multi-identity not the totality of the code, in the simulation we used one identity matrix, the FBG filter is followed by a photodetector (PD), then a low-pass filter (LPF) of 0.75 GHz and finally an error detector. Here, the data rate is 622 Mb/s for each user and the transmit power used was -10 dBm. The noise at the receivers was considered random and totally uncorrelated. The dark current value is 5 nA, and the coefficient of thermal noise is 1.8×10-23 W / Hz for each of the photodetectors. BER and eye diagram are used as a quality criterion for measuring the SAC-OCDMA performance system.

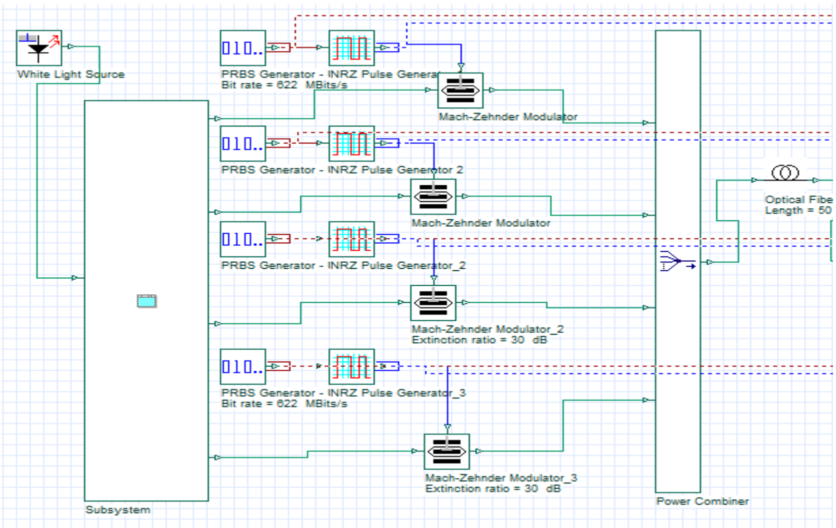

Figure 3. Block diagram of SAC OCDMA system (coding part)

As explained in Section 3, the main advantage of this technique is that no subtractors are used at the receiver, and even the number of filters is greatly reduced. Using the spectral direct detection technique the system performance is improved. The tests were carried out for a distance equal to 50 km, 100 km and 115 km (Figure 6, 7, 8), with a standard single-mode optical fiber (SMF) of the ITU-T G.652.

All the attenuations and nonlinear effects were activated and specified as in [12-13].
The eye diagram of the first user for the system code MIHP is shown in figure 6. It is clearly that the MIHP code system gives better performance, having a large eye opening and gave a BER (8.70886e-17) without using any amplifier. The more eye close, the harder it is to differentiate between ones and zeros in the signal.

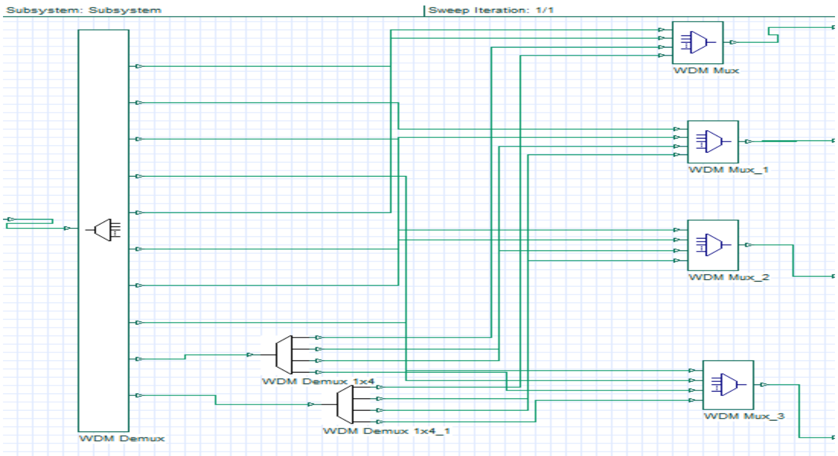

Figure 4. Spectral signature code using a mux and demux

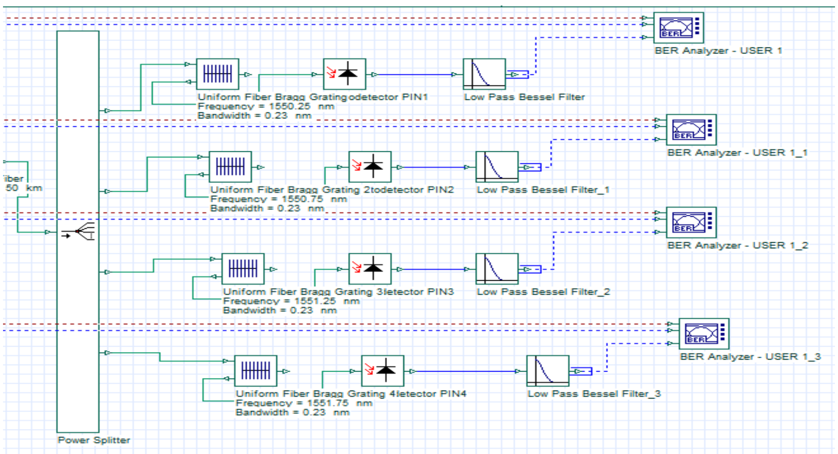

Figure 5. Block diagram of SAC OCDMA system (reception part)

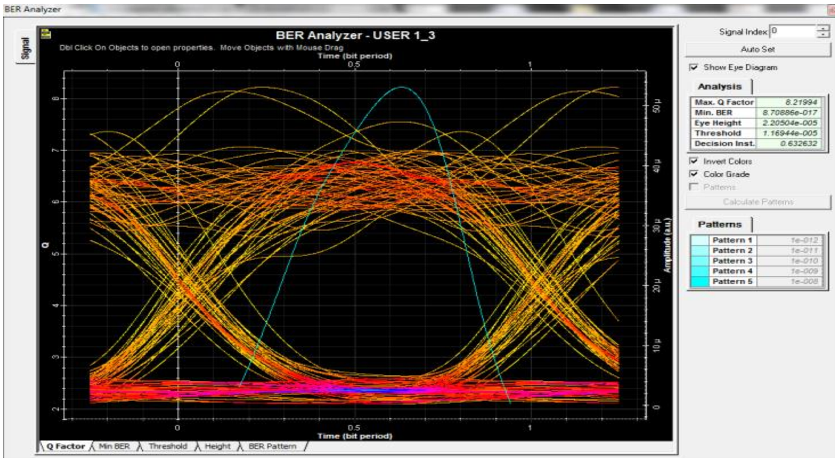

Figure 6. The eye diagram of the first user for a distance equal to 50 km

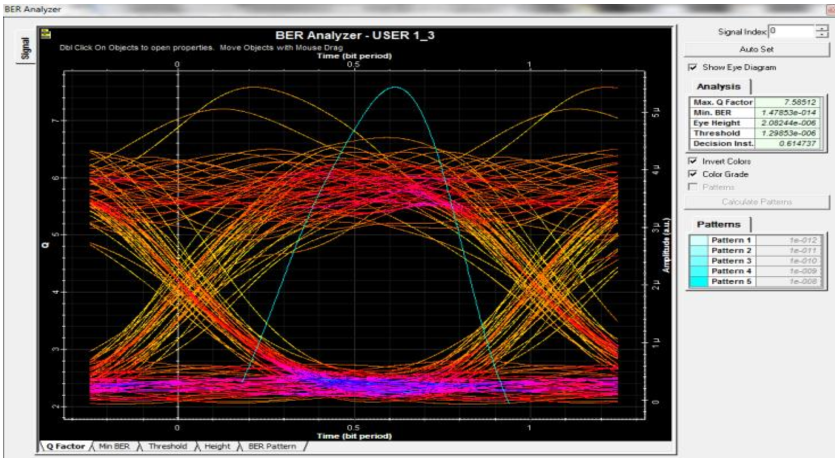

Figure 7. The eye diagram of the first user for a distance equal to 100 km

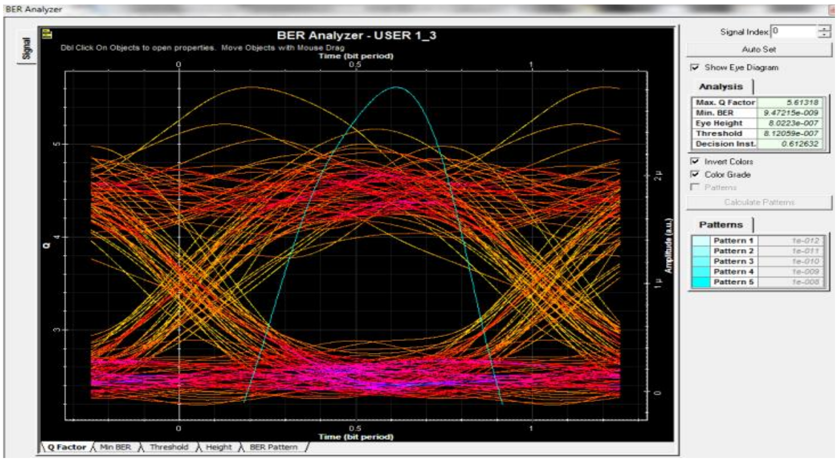

Figure 8. The eye diagram of the first user for a distance equal to 115 km

5. Conclusion

The OCDMA system performance is degraded when the number of users is important. This is due to the multiple access interference (MAI) which results from incomplete orthogonality.
In this article, the major contribution of the MIHP code is the elimination of the interference MAI, and it has been demonstrated that by using a direct detection technique, MIHP code will behave similarly as a code with zero cross-correlation this property improves system performance. The results demonstrate that the MIHP code allows multiplexing of multiple users. Simulation results of the four users using MIHP codes, which have been made for distances equal to 50km, 100km and 115km with a standard single mode optical fiber, have shown a very good quality transmission.

As a result, the code MIHP is very suitable for use in the access and OCDMA systems gives an additional selection in OCDMA scheme.

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