Performance analysis of Optical CDMA System Based on Zero Cross Correlation (ZCC) Code using OFDM Modulation

A .Cherifi [1], B. Yagoubi [2], B. S. Bouazza [1] , A.O.Dahman[3].
[1]Technology of Communication Laboratory (LTC)
University Of Tahar Moulay Saida
Algeria
[2]University of Abdelhamid Ibn Badis
Mostaganem
Algeria
[3]Laboratory of Microsystems and Telecommunications (LMST)
University Of Quebec
Canada
Cherifi.abdelhamid@gmail.com sbmsvy@gmail.com master2005_78@yahoo.fr dahmane@uqtr.ca

Abstract: - In order to increase the number of users and data rate, and to reduce the impact of multi access interference (MAI), this study propose the optical code division multiple access (OCDMA) systems with orthogonal frequency division multiplexing modulation (OFDM) based on new zero cross correlation (ZCC) code .

The system proposed (OCDMA- new ZCC-OFDM) is compared to the (OCDMA-FCC (Flexible Cross Correlation)-OFDM) in term of SNR and BER. The results showed that the proposed system with the new ZCC code displayed improved performance with an increased number of users up to 120%. The system adopted saved around -3 dBm of power at the receiver. In comparison to (OCDMA-FCC-OFDM) system, this improvement is due to the effect of the good auto/cross correlation properties of new ZCC code.

Key-Words: - Optical CDMA, OFDM, New ZCC code, Flexible Cross Correlation (FCC) code, (OCDMA-FCC-OFDM) systems, (OCDMA-new ZCC-OFDM) systems.

1 Introduction

Optical code-division multiple-access (OCDMA) is receiving increasing attention due to its potential for enhanced information security, simplified and decentralized network control, improved spectral efficiency [1].

The main advantages of OCDMA are to provide multiple simultaneous users with the same bandwidth along with high security, and to improve optical communication applications [2]. It can be considered as a good solution for optical networks. So, to obtain the best spectral efficiency possible at reduced cost, a practical optical system that combines the technical orthogonal frequency division multiplexing (OFDM) and CDMA is used to enhance the data rate transmission and to increase the number of simultaneous users. This combination has received increased attention as a means to overcome various limitations of optical transmission systems, such as the multipath dispersion and multi access interference (MAI).

OFDM has become a popular transmission technique for high-data-rate wireless communications in recent years due to its high spectral efficiency and good resistance to multipath fading [3].

OFDM is considered an effective technique for broadband wireless communications because of its great immunity to fast fading channels and inter-symbol interference (ISI) [4].

Thus, by using this method, we can get better spectrum utilization, increase transmission rate, and also generate higher number of sub-carrier.

In this article, we examined and evaluated the advantages of (OCDMA-new ZCC –OFDM) Optical system. The SNR expression was derived by taking into account the non-linearity of subcarriers using the new ZCC code. OFDM modulation provided many orthogonal subcarriers which are transmitted to a single optical fiber.In reception part, the desired user will be detected from few subcarriers by using the optical filters (FBG narrowband), the code signature, similar to those using in emission part. The use of this filter removes the effect of multi access interference. The main goal of this study is to combine OFDM technique with (new ZCC-OCDMA) system to improve the performance of optical network. In other side, the results of the proposed technique (OCDMA -new ZCC-OFDM) are compared to the work (OCDMA-FCC (Flexible Cross Correlation)-OFDM) reported by A.O. Aldhaibani and al in [5]. This paper is organized as follows. In Section 2 provides (OCDMA –OFDM) system based on new ZCC code. In Section (3) OCDMA- OFDM performances are presented. Section 4 Simulation results are presented. And the Conclusions are drawn in Section 5.

2 Principle of OCDMA-OFDM system

In the part of OFDM signal, data bits are encoded using a QAM constellation, this electrical signal passes through the IFFT block, the guard interval is inserted between these block. This eliminates interference between successive blocks in the presence of multipath channels and facilitates the more equalization.

Each OFDM symbols are modulated with the optical ZCC code by using the external modulator. This code is implemented by the Wavelength Division Multiplexing (WDM) like a Fiber Bragg grating (FBGs) which is a technique used in optical communications. This allows transmitting several wavelength signals on a single optical fiber. In the receiver part, the received signal is detected by the photo-detector (see Fig.1).

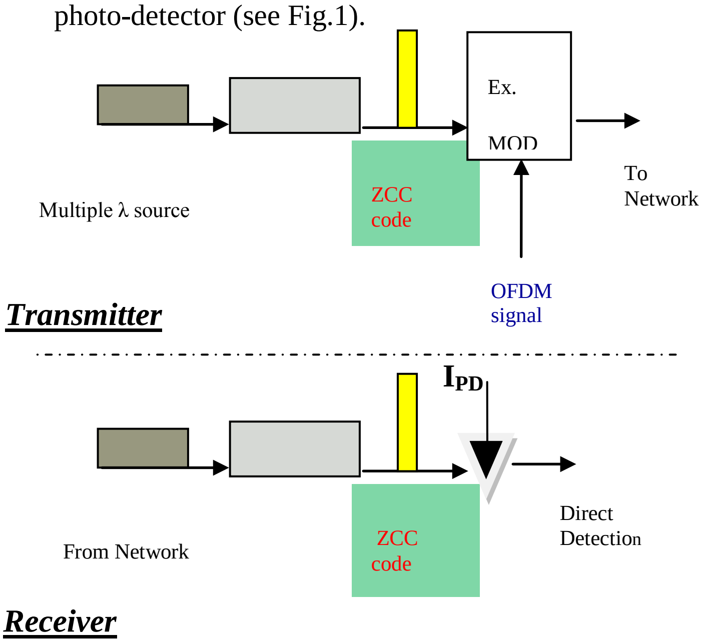

Fig.1 Scheme illustrates the (OFDM-OCDMA) system.

Finally, the signal can be recovered after using OFDM demodulator, FFT operations, matched filtering and other electrical treatments.

3 OCDMA-OFDM performances

To analyze and evaluate the performance of the proposed method (OFDM -CDMA optical) with the new ZCC code, the Gaussian approximation for computing the signal to noise ratio (SNR) and bit error rate (BER) was used. As shown in fig 1, SNR is expressed by: $SNR = \frac{I^2}{\sigma^2}$, where I^2: represent the current received at the photodiode given by $I^2 = I_{sh}^2 + I_{th}^2$ and σ^2 is the variance of the noise signal. The effect of phase induced intensity noise (PIIN) is neglected due to the zero cross correlation condition with no overlapping of spectra from multiuser [6], [7]. The first stage concerns with studying the design of the new ZCC code. The general form of ZCC code is:

$$ZCC1=\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \quad (1)$$

We use the mapping technique in ZCC code to avoid the overlapping of 1 for both users, in addition to increasing both; the number of users and the code length.

$$ZCCn=\begin{bmatrix} 0 & ZCC_{n-1} \\ ZCC_{n-1} & 0 \end{bmatrix} \quad (2)$$

Example:

$$ZCC2=\begin{bmatrix} 0 & ZCC_1 \\ ZCC_1 & 0 \end{bmatrix}$$

$$ZCC2=\begin{bmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$$

Regarding the mapping phase, the relationship between the three parameters (the number of user “K”, the code length “C” and the number of mapping process “M= W" where W represents the code-weight) is given as follows:

$$K_M = 2^M$$

$$C_M = 2^M \times w$$

To extend the number of weight and transform the code w = "N-1" to w = N, (N ≥2), several methods are proposed [4], [5], [8], [9].

The ZCC code properties for Direct Detection technique is given as :

$$\sum_{i=1}^{N} C_k(i).C_l(i)=\begin{cases} w, & \text{for } K = l \\ 0, & \text{else} \end{cases} \quad (3)$$

Let $C_k(i)$ denote the ith element of new Zcc code sequence with weight w. K denotes the number of each user, in fig. 2, All users send the same data bits ($d_m = \frac{w}{L}$) equal to "1". With $\sum_{k=1}^{K} d_k = d_1 + \cdots + d_K = K \times \frac{w}{L} = 1$ (4)

The power spectral density (PSD) at the receiving end during a single bit period for PIN photodiode detection can be defined as follows [7, 8]:

$$r(v) = \frac{P_{sr}}{\Delta v} \sum_{k=1}^{K} d_k \sum_{i=1}^{L} C_k(i).C_l(i).rec(i) \quad (5)$$

$$r(v) = \frac{P_{sr}}{\Delta v} \sum_{k=1}^{K} d_k \sum_{i=1}^{L} C_k(i) C_l(i) \left\{ U\left[v - v_0 - \frac{\Delta v}{2L}(-L + 2i - 2)\right] - U\left[v - v_0 - \frac{\Delta v}{2L}(-L + 2i)\right] \right.$$

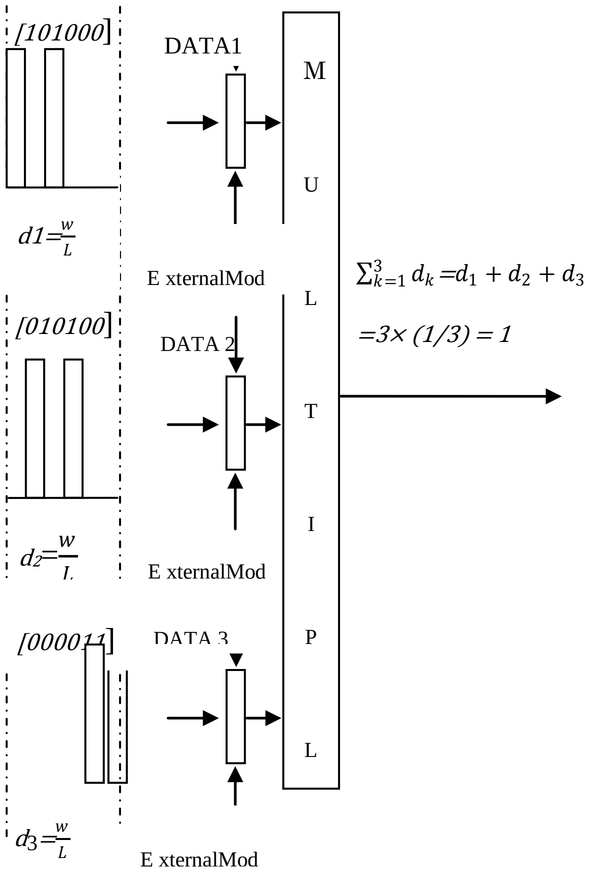

Fig.2 Block diagram of a new ZCC code transmitter system.

Where Psr is the power received of a broadband source and u (v) represents a unit step function is equal to: $U(v) = \begin{cases} 0, & v < 0 \\ 1, & v \geq 0 \end{cases}$

Then, integrating equation of the PSD can be determined by:

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

$$= \frac{P_{sr}}{\Delta v}\left[\underbrace{\sum_{k=1}^{K} d_k . w . \frac{\Delta v}{L}}_{L=k} + \underbrace{\sum_{k=1}^{K} d_k . 0 . \frac{\Delta v}{L}}_{l \neq k}\right] \quad (7)$$

From Eq. (4), when all the users are transmitting bit "1" , sing the average value as:

$$\sum_{k=1}^{K} d_k = d_1 + \cdots + d_K = K \times \frac{w}{L} = 1$$

$$\text{so:} \int_0^{+\infty} r(v)dv = \frac{P_{sr} W^2}{L} \quad (8)$$

The photocurrent Idd can be expressed as:

$$I_{dd} = \Re \int_0^{+\infty} r(v)dv = \frac{\Re . P_{sr} . w}{L} \quad (9)$$

Where $\Re$ represents the responsively of the PDs given by: $\Re = {\eta . e}/{h . v_0}$ Here, η is the quantum efficiency, e isthe electron's charge, h is the Plank's constant ($6{,}626068 \times 10^{-34}$ m^2 kg / s), and $v_0$is the central frequency of broad-band optical pulse [8].

$$[I_{dd}]^2 = \left(\frac{\Re . P_{sr} . w}{L}\right)^2 \quad (10)$$

In demodulate OFDM signal phase. Signal received of photocurrent (I_{dd}) can be expressed as

$$[I_{dd}]^2 = \left(\frac{\Re . P_{sr} . w}{L}\right)^2 . \sum_{n=1}^{k} C_n \, e^{j2\pi f_n t} . \quad n=1, 2, k \quad (11)$$

The orthogonality conditions are put to ensure the absence of interference between the different carriers which is given by the following

Expression [10]. $f_n = \frac{n-1}{k}$

The noise power of PIN can be written as:

$$I^2 = I_{sh}^2 + I_{th}^2 \quad (12)$$

Where I_{sh} : Shot noise $I_{sh}^2 = 2 \, e \, B \, I_{dd}$

AndI_{th}: Thermal noise

$$I_{th}^2 = \frac{4 \, K_b T_{nB}}{R_l} \quad (13)$$

Noting that the probability of sending bit '1' at any time by each subscriber is ½ [11], than Eq. (11) becomes:

$$I^2 = \frac{\Re . e \,.\, B . P_{sr} . w}{L} + \frac{4 \, K_b T_{nB}}{R_l} \quad (14)$$

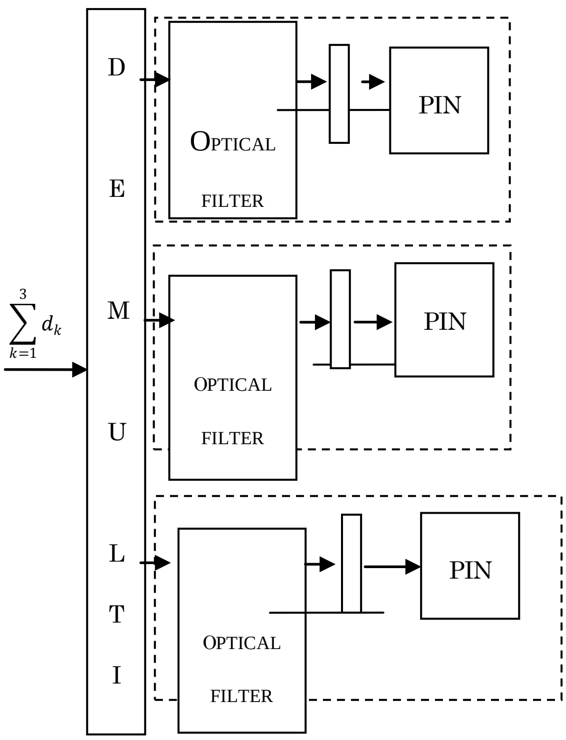

Fig.3 diagram illustrates the new ZCC code receiver system.

Now using equations (10), (12) and (13), the signal to noise ratio (SNR) of direct detection technique by using the value of proprieties in [11]; the new expression of SNR can be written as:

$$\mathrm{SNR} = \frac{[I_{dd}]^2}{I^2} = \frac{\left(\frac{\Re P_{sr} w}{L} \sum_{n=1}^{k} C_n e^{j2\pi f n t}\right)^2}{\frac{eB\,\Re P_{sr} w}{L} + \frac{4 K_b T_n B}{R_l}} \qquad (15)$$

Thus BER can be obtained as: $\mathrm{BER} = \frac{1}{2}\operatorname{erfc}\sqrt{\frac{\mathrm{SNR}}{8}}$

Table 1, parameters used in the calculation of the proposed systems.

Photodetector quantum efficiency(η)	0.6
Line-widthbroadband source (Δv)	3.75 THz
Operating wavelength (λ0)	1550 nm
Electrical band width(B)	311 MHz
Data bit rate(Rb)	622 Mbps
Receiver noise temperature(T_n)	300 K
Receiver load resistor (R_l)	1030 Ω
Number of subcarriers(k)	256

4. Numerical results

In order to evaluate the performance of new ZCC code using (OFDM-OCDMA) systems, the current study used the same parameters previously reported [2, 6, 12] . Table 1 indicates the chosen parameters for the calculation of new ZCC code to reduce the BER and to increase the number of simultaneous users, and to improve the power received. These results were simulated using matlab. The weight used in optical system (OCDMA-OFDM) for this study is w=4 at data rate 622Mbps and power received equal to -20 dBm. We found in a study by A.O. Aldhaibani [5] that the authors used B=0.75R…. (*), R bit rate. But in table 1 it was mentioned that the electrical bandwidth was B=311.so, due to the calculation of the equation… (*) we find that B=0.5R is the right value. In our study, B=311 was used in comparison to the A.O. Aldhaibani results [5].

Fig 4.shows the variations of the BER with the number of users (k) for (OCDMA-OFDM) systems using the two codes (new ZCC code and FCC Code)

We observe that the BER of proposed system using new ZCC code has better performance than using FCC code; this enhancement is due to effect of the new ZCC codes length and the good proprieties of auto and Cross correlation. At the acceptable BER (10^{-9}), we note that the number of simultaneous users (OCDMA-OFDM code -new ZCC) and (OCDMA-OFDM - FCC Code) are respectively 107 and 100; we say that the cardinality has increased up to 10.7% when we use the new ZCC code.

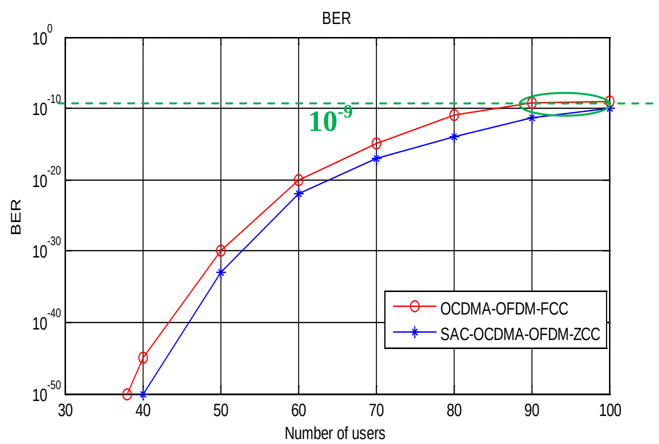

Fig.4, BER against number of users for ODCMA-OFDM systems using two codes (New ZCC) code and (FCC) code With (W= 4).

Fig.5. represents the BER against the received power for the two systems (OFDM-OCDMA-new ZCC) and (OFDM-OCDMA-FCC) at 622 Mbps of data rate and at k=50 (k the number of users) . We observe that the power received for (OFDM-OCDMA-new ZCC) and (OFDM-OCDMA-FCC) are -24dBms and -27dBms respectively at the acceptable BER(10^{-9}), Therefore, when we use (OFDM-OCDMA-new ZCC) system, the performances become better compared with

(OFDM-OCDMA-FCC) and we can save around -3 dBm of power.

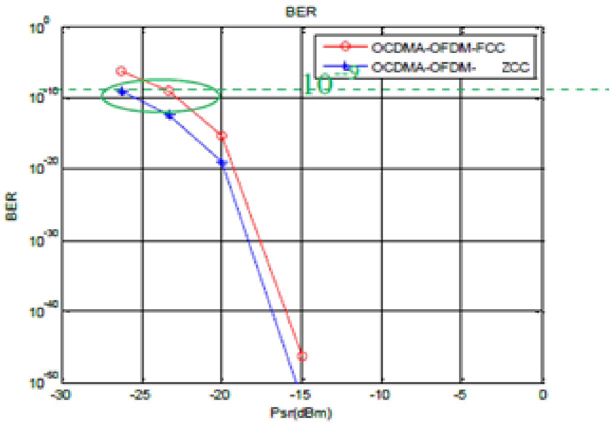

Fig.5 BER against power receive (Psr) for ODCMA-OFDM systems using two codes (New ZCC)code and(Fcc) code at 622 Mbps data rate and (W=4).

Fig.6 represents the BER as a function of number of users at acceptable BER (10^{-9}) when we fix Psr= -20dB.the BER expression is given by the electrical bandwidth of direct detection (b=0.5R), R: bit rate. We notice that within 2.5 GB for (OFDM-OCDMA-new ZCC) we obtain 107 users compared with (OFDM-OCDMA-FCC) which is 100 users. Thus, within 10GB for (OFDM-OCDMA-new ZCC) we obtain 68 users compared with (OFDM-OCDMA-FCC) which is 43 users, apparently the proposed system using the new ZCC code has better performance than using the FCCcode.

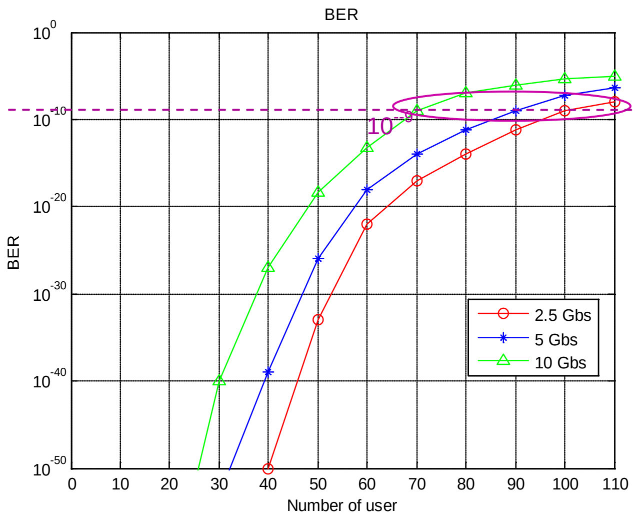

Fig.6 BER against number of users for ODCMA-OFDM systems using new ZCC code (w=4)

5 Conclusion

In this paper, we have derived an analytical expression of SNR of OCDMA- OFDM systems based on new ZCC code. The performance are evaluated in terms of BER, the proposed system with the new ZCC code provided better performance compared to FCC code. The major advantage of proposed code has short code lengths and the large flexibility proprieties.

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