New Method for the Construction of Optical Zero Cross Correlation Code Using Block Matrices in OCDMA-OFDM System

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***Abstract*— In order to increase the number of users and data rate, and to reduce the impact of multi access interference (MAI), this study proposes the optical code division multiple access (OCDMA) systems with orthogonal frequency division multiplexing modulation (OFDM) based on a new zero cross correlation (ZCC) code. The OCDMA, a new ZCC-OFDM suggested system, was compared to the OCDMA-FCC (Flexible Cross Correlation)-OFDM in terms of signal to noise ratio (SNR) and bit error rate (BER). The results showed that the proposed system with the new ZCC code improves the system capacity performance by increasing the number of simultaneous users (cardinality) up to approximately 120% as compared to SCM (subcarrier multiplexing) OCDMA-FCC, and up to 7% in comparison to OCDMA-FCC (Flexible Cross Correlation)-OFDM. The adopted system has superior performance by saving around -3 dBm of power at the receiver with better bit error rate in comparison to OCDMA-FCC-OFDM system. In addition, the resulting power due to the increased number of users using our proposed new ZCC code is less in comparison to the FCC code. This improvement is due to the effect of the good auto/cross correlation properties of the new ZCC code.**

***Index Terms*— Optical CDMA, OFDM, New ZCC code, Flexible Cross Correlation (FCC) code, OCDMA-FCC-OFDM systems, OCDMA-New ZCC-OFDM systems.**

I. INTRODUCTION

Currently, the most common way to allow several transmitters to send information at the same time by a single channel is code division multiple access (CDMA). It is a unique code given to each transmitter; a spread spectrum technique by the same physical resources. 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 [1]. It can be considered as a good solution for optical networks. Thus, to obtain the best spectral efficiency possible at a 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 [2]. Thus, by using this method, we can get a better utilization of spectrum, increase the transmission rate, and generate higher number of sub-carrier. In this article, we examined and evaluated the advantages of (OCDMA-new ZCC–OFDM) Optical system. The expression SNR was derived by taking into account the non-linearity of subcarriers using a new ZCC code. OFDM modulation provided many orthogonal subcarriers, which are transmitted to a single optical fiber. In the reception part, the desired user will be detected from a few subcarriers by using the optical filters (FBG narrowband), the code signature, similar to those using in the 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 a system (new ZCC-OCDMA) to improve the performance of optical network. The results of the proposed technique (OCDMA-new ZCC-OFDM) has been reported by A.O. Aldhaibani et al. in [4]. This paper is organized as follows: Section II provides (OCDMA –OFDM) system based on the new ZCC code. In Section III, the performances of OCDMA-OFDM are presented. Section IV introduces our proposed design of the new ZCC codes, their properties and performances. In Section V, results of the simulation are presented and the conclusions are drawn in Section VI.

II. 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, and then the guard interval is inserted between these blocks. This eliminates interference between successive blocks in the presence of multipath channels and facilitates more equalization.

Each OFDM symbols is modulated with an optical ZCC code using the external modulator. This code is implemented by the Wavelength Division Multiplexing (WDM), such as 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 Figure 1).

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

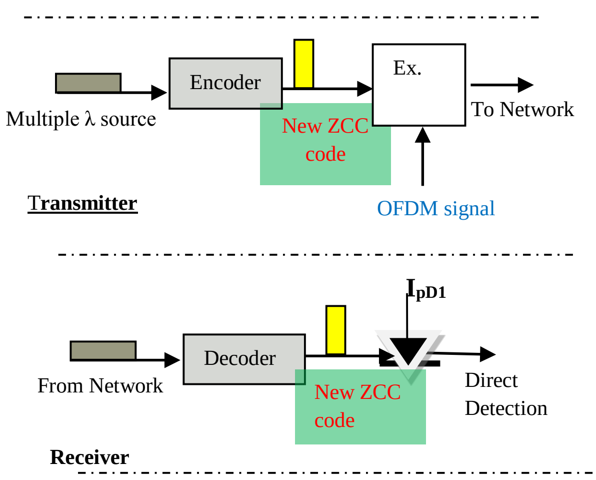

Figure 1: Scheme illustrates the (OFDM-OCDMA) system

III. OCDMA-OFDM PERFORMANCE

To analyze and evaluate the performance of the proposed method (OFDM -CDMA optical) with the new ZCC code, Gaussian approximation for computing the signal to noise ratio (SNR) and bit error rate (BER) was used. As shown in Figure 1, SNR is expressed by: $SNR=\frac{I^2}{\sigma^2}$ where I^2: represents 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 the induced intensity noise (PIIN) phase is neglected due to the zero cross correlation condition with no overlapping of spectra from multi-user [5], [6]. The first stage concerns with studying the design of the new ZCC code. The general form of ZCC code is:

$$ZCC1=\begin{bmatrix}0 & 1\\ 1 & 0\end{bmatrix} \tag{1}$$

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

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

For example:

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

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

$$Km = 2^M$$
$$Cm = 2^M xw$$

To extend the number of weight and transform the code w = "N-1" to w = N, (N ≥2), the matrix form is given by:

$$ZCCN=\begin{bmatrix}A & B\\ C & D\end{bmatrix} \tag{3}$$

where: [A] comprises a matrix of [2, 2 × w], in which this matrix contains the w replication of the matrix (Zw-1).
[B] comprises a matrix of zero of [2, 2 × w].
[C] comprises a matrix of zero of [(K−2), w×2].
[D] comprises a matrix of zero of [(K−2), w× (K−2)]

Taking an example for k = 3, the transformation code for w = 1 to w= 2 are presented as:

$$ZCC2=\left[\begin{array}{c|ccccc}0 & 1 & 0 & 1 & 0 & 0\\ 1 & 0 & 1 & 0 & 0 & 0\\ \hline 0 & 0 & 0 & 0 & 1 & 1\end{array}\right]$$

where the expression between w, k and C is defined by:

$$C = W \times K \tag{4}$$

To increase the number of users and the code length without modifying the weight, a mapping technique is used as:

$$ZCCm=\begin{bmatrix}0 & ZCC_{m-1}\\ ZCC_{m-1} & 0\end{bmatrix} \tag{5}$$

The expression of the equation which connects the coefficients of mapping (mapped number of users' Cm, the code length Lm and the mapping processes m) are expressed as:

$$\begin{aligned}Cm &= 2^M \times (CB)\\ Lm &= 2^M \times (L)\end{aligned} \tag{6}$$

IV. THE PROPOSED DESIGN

The newly proposed ZCC code is represented in a matrix K×C, the construction method is as follows:

$$ZCC=\begin{bmatrix}Z_i\\ Rot180^0(Z_i)\end{bmatrix} \tag{7}$$

where Z_i is the half matrix; consist of $(\frac{k}{2}, k \times w)$, the construction of half matrix is given by:

$$Z(\frac{k}{2}, k \times w) = \begin{bmatrix} c_1 \\ \vdots \\ c_i \\ \vdots \\ c_{\frac{k}{2}} \end{bmatrix} \tag{8}$$

where $1 \le i \le \frac{k}{2}$.

The code C_i has $(k \times w)$ chips, w Chips"1" and "$(k \times w) - w$ chips '0. So we can write:

$$c_{ij} = i + (\frac{k}{2} \times j)$$

where, $0 \le j \le w-1$.

$$Z_I = \begin{Bmatrix} C_i, \ for; i; odd \\ Rot180^o(c_i), \ for, i, even \end{Bmatrix} \tag{9}$$

The other half of the matrix is the rotation of 180^0 of the matrix Z_I. So, the ZCC code is:

$$ZCC = \begin{bmatrix} Z_i \\ Rot180^0(Z_i) \end{bmatrix} \tag{10}$$

For example, let K=6 and w = 2 and the wave length is limited to 12. The generation of the half matrix is shown in Table 1.

Table 1
The positions of '1' in New ZCC matrix

i	J	
	0	1
i=1	1	4
i=2	2	5
i=3	3	6

The half matrix is:

$$z_i = \begin{bmatrix} 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{11}$$

The matrix is the rotation of 180^0 of the matrix Zi:

$$rot180^0(Z_i) = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 \end{bmatrix} \tag{12}$$

The ZCC code is given by:

$$ZCC = \begin{bmatrix} 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 \end{bmatrix} \tag{13}$$

Z_i

$rot180^0(z_i)$

The relation between the different parameters is given by Equation 4.

Table 2
Codes length of ZCC ([4] , [7] , [8] ,[9] , [10]) code, FCC code and new ZCC code

Codes	Code length (C)	Cross correlation
ZCC [7]	C = W×(W + 1) K = W + 1	0
ZCC[4]-[8]	Cm= 2m.C Km= 2m.K With m = W	0
ZCC[9]-[10]	C = W × K	0
FCC code	C = (W × K) - (K-1)	0
Proposed ZCC code	C = W × K	0

The properties comparison of the different construction methods of ZCC codes and the new ZCC codes are listed in Table 2. Table 2 shows the code length required by the different codes with zero cross-correlation. We can remark that the proposed ZCC has good code length compared to the other methods. Long code lengths are considered as disadvantageous, but the proposed method is easier to construct. The new ZCC code properties for Direct Detection technique is given as:

$$\sum_{i=1}^{N} C_K(i).C_l(i) \begin{Bmatrix} w, \ for, k=1 \\ 0, else \end{Bmatrix} \tag{14}$$

Let $C_k(i)$ denotes the *i*-th element of new ZCC code sequence with weight w. K denotes the number of each user, in Figure 2, all users send the same data bits $d_m = \frac{w}{L}$ equal to "1". With:

$$\sum_{K=1}^{K} d_k = d_1 + \ldots\ldots + d_K = K \times \frac{w}{L} = 1, \tag{15}$$

The power spectral density (PSD) at the receiving end during a single bit period for PIN photodiode detection can be defined as follows [11, 12]:

$$r(v)=\frac{p_{sr}}{\Delta v}\sum_{K=1}^{K}d_K\sum_{i=1}^{L}C_K(i).C_l(i).rec(i)$$

$$r(v)=\frac{p_{sr}}{\Delta v}\sum_{K=1}^{K}d_K\sum_{i=1}^{L}C_K(i).C_l(i)\left\{U\left[\begin{matrix}v-v_0-\dfrac{\Delta v}{2L}\\(-L+2i-2)\end{matrix}\right]\right. \tag{16}$$

$$\left.-U\left[v-v_0-\frac{\Delta v}{2}(-L+2i)\right]\right\}$$

where P_{sr} is the power received of a broadband source and u (v) represents a unit step function:

$$U(v)=\begin{Bmatrix}0, v\langle 0\\1, v\geq 0\end{Bmatrix}$$

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

$$\int_0^{+\infty}r(v)dv=\int_0^{+\infty}\frac{p_{sr}}{\Delta v}\sum_{K=1}^{K}d_K\sum_{i=1}^{L}C_K(i)C_l(i)U(\frac{\Delta v}{L}) \tag{17}$$

$$=\frac{P_{Sr}}{\Delta v}\left[\underbrace{\sum_{K=1}^{K}d_K.w.\frac{\Delta v}{L}}_{L=K}+\underbrace{\sum_{K=1}^{K}d_K.0.(\frac{\Delta v}{L})}_{L\neq K}\right] \tag{18}$$

From Equation 18, when all the users are transmitting bit “1,” using the average value as:

$$\sum_{K=1}^{K}d_k=d_1+........+d_K=K\times\frac{w}{L}=1,$$
$$so:\int_0^{+\infty}r(v)dv=\frac{P_{Sr}w^2}{L} \tag{19}$$

The photocurrent, Idd can be expressed as:

$$I_{dd}=\Re\int_0^{+\infty}r(v)dv=\frac{\Re P_{Sr}.w}{L} \tag{20}$$

where $\Re$ represents the response of the PDs given $\Re=\eta.e/h.v_0$. Here, η is the quantum efficiency, e is the electron’s charge, h is the Plank’s constant 6,626068×10⁻³⁴ m² kg / s), and v_0 is the central frequency of broad-band optical pulse [13] .

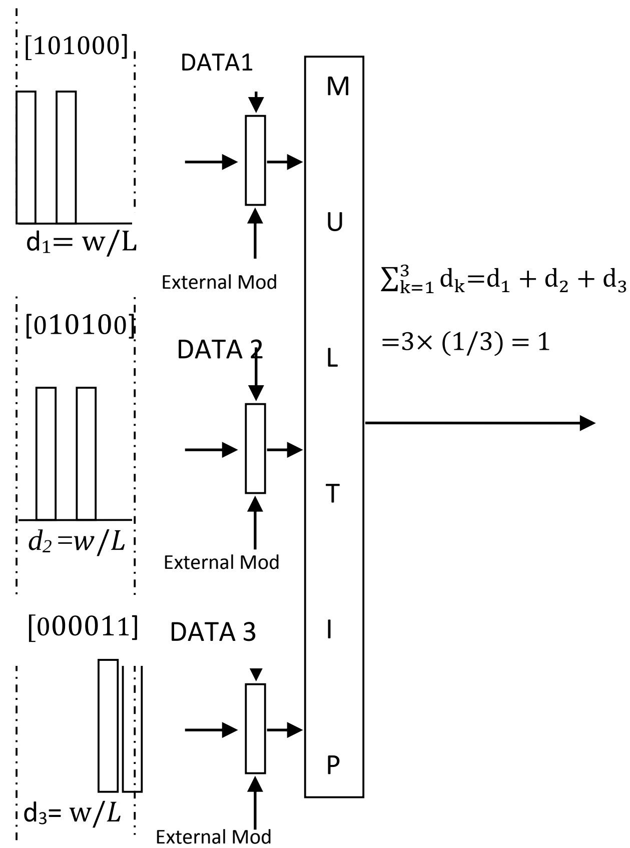

Figure 2: Block diagram of a new ZCC code transmitter system.

$$[I_{dd}]^2=(\frac{\Re P_{Sr}.w}{L})^2 \tag{21}$$

The OFDM signal demodulation phase, which is the signal received by the photocurrent (I_{dd}) can be expressed as:

$$[I_{dd}]^2=(\frac{\Re P_{Sr}.w}{L})^2.\sum_{n=1}^{K}C_ne^{j2\pi f_nt}, n=1,2....,k \tag{22}$$

The orthogonality conditions are put to ensure the absence of interference between the different carriers, which is given by the following expression [14].

$$f_n=\frac{n-1}{k}$$

The noise power of PIN can be written as:

$$I^2=I_{Sh}{}^2+I_{th}{}^2 \tag{23}$$

where I_{Sh} = Shot noise,

$I^2=2eBI_{dd}$

I_{th}: Thermal noise

$$I_{th}^{\ 2} = \frac{4K_b T_{nB}}{R_l} \tag{24}$$

Noting that the probability of sending bit ‘1’ at any time by each subscriber is ½ [15], then Equation 23 becomes:

$$I^2 = \frac{\Re.e.B.P_{Sr}.w}{L} + \frac{4K_b T_{nB}}{R_l} \tag{25}$$

Now using Equations 21, 23 and 24, the signal to noise ratio (SNR) of direct detection technique is derived by using the value of properties in [15]; the new expression of SNR can be written as:

$$SNR = \frac{[I_{dd}]^2}{I^2} = \frac{\left(\frac{\Re P_{Sr}.w}{L}.\sum_{n=1}^{K} C_n e^{j2\pi f_n t}\right)^2}{\frac{e.B\Re..P_{Sr}.w}{L} + \frac{4K_b T_{nB}}{R_l}} \tag{26}$$

Thus, BER can be obtained as:

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

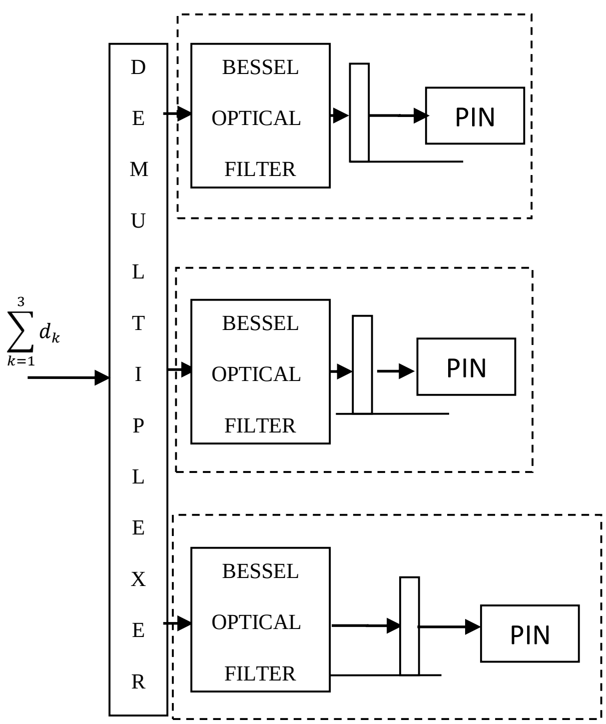

Figure 3: ZCC code receiver system

Table 3
Parameters used in the calculation of the proposed systems

Parameters	Value
Photodetector quantum efficiency(η)	0.6
Line-width broadband source (Δv)	3.75 THz
Operating wavelength (λ0)	1550 nm
Electrical band width(B)	311 MHz
Data bit rate(R_b)	622 Mbps
Receiver noise temperature(T_n)	300 K
Receiver load resistor (R_l)	1030 Ω
Number of subcarriers(k)	256
Electron charge (e)	1.6 x10^{-19} c
Planck’s constant (h)	1.38 x 10^{-23} J/K
Boltzmann’s constant (Kb)	6.66 x10^{-34} Js

V. 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 in [1, 4, 16, and 17]. Table 3 indicates the chosen parameters for the calculation of the new ZCC code to reduce the BER, 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 have used Table 3, which is a same as Table 1 of A.O. Aldhaibani et al. [4], so, if we take a look at Table 1 in A.O. Aldhaibani et. al. [4] we can read (B=311 MHz) and (R=622 Mbps), whereas using their formula (B=0.75R), we found, B=446.5MHz which is incorrect. In order to obtain the exact value of B=311MHz, which is mentioned in Table 3 and in Table 1 of A.O. Aldhaibani [4], we should use B=0.5R instead of B=0.75R.

In a case, where responsivity of the photodiode = 0.5, R is the bit rate (R=622 Mbps) and B is the electrical bandwidth (B=311 MHz).nFigure 4 shows the variations of the BER with the number of users k for OCDMA-OFDM systems using the two codes: the new ZCC code and FCC Code .We observe that the BER of the proposed system using the new ZCC code has better performance than using FCC code. This enhancement is due to the effect of the new ZCC codes length and the good properties of auto and cross correlation. At an acceptable BER of 10^{-9}, we note that the number of simultaneous users for OCDMA-OFDM code - new ZCC and OCDMA-OFDM - FCC Code are 107 and 100 respectively; we said that the cardinality has increased up to 7 % when we use the new ZCC Code, so, the amelioration of the rate of our system performance (cardinality) is increased in terms of number of user is calculated as follows:

$$\frac{107 - 100}{100} = 7\%$$

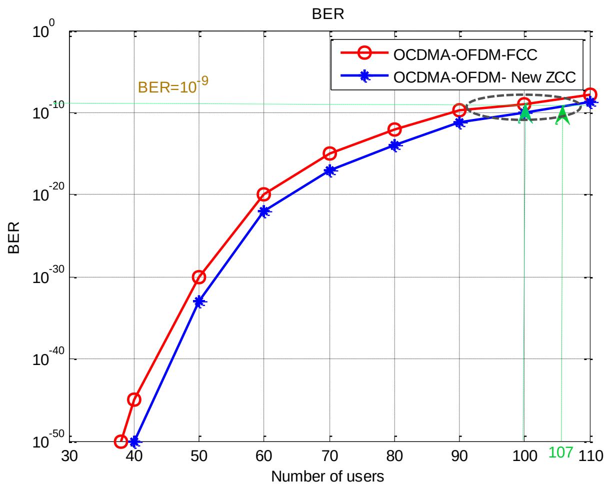

Figure 4: BER against number of users for OCDMA-OFDM systems using two codes (New ZCC) code and (FCC) code With (W= 4)

Figure 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 is the number of users). We observed that the power received for OFDM-OCDMA-new ZCC and OFDM-OCDMA-FCC are -24 dBm and -27dBm respectively at the acceptable BER (10^{-9}), Therefore, when we use OFDM-OCDMA-new ZCC system, the performance becomes better compared to FDM-OCDMA-FCC and we can save around -3 dBm of power, the system performance in terms of power receiver is calculated as follows: (-27 – (-24)) = -3 dBm).

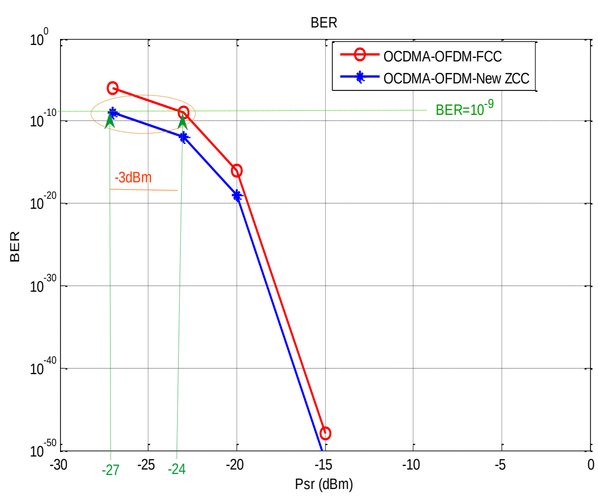

Figure 5: BER against power receive (Psr) for ODCMA-OFDM systems using two codes (New ZCC)code and(FCC) code at 622 Mbps data rate and (W=4)

Figure 6 represents the BER as a function of number of users at an acceptable BER of 10^{-9} when we fix Psr at -20dBm. The BER expression is given by the electrical bandwidth of direct detection (B=0.5R), and R is the bit rate. We notice that at the data rate for 2.5 Gbs, OFDM-OCDMA-new ZCC, we obtain 107 users compared to OFDM-OCDMA-FCC, which is 100 users in A.O. Aldhaibani et al. [4]. Thus, at the data rate for 10Gbs, OFDM-OCDMA-new ZCC, we obtain 78 users compared to OFDM-OCDMA-FCC, which is 43 users in A.O. Aldhaibani et al. [4]. Apparently the proposed system using the new ZCC code has better performance than using the FCC code.

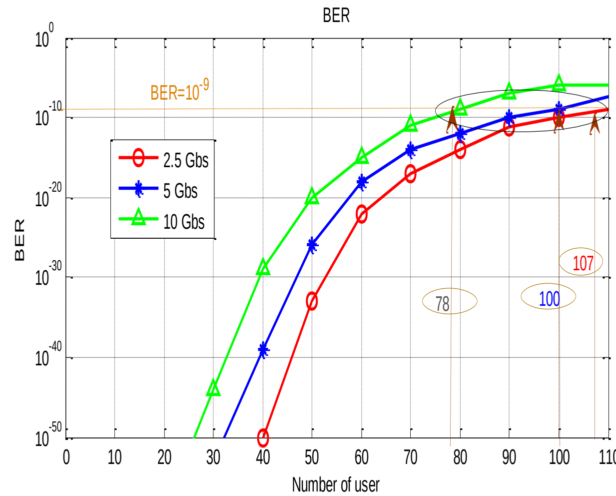

Figure 6: BER against number of users for ODCMA-OFDM systems using new ZCC code (w=4).

Figure 7 indicates the performance comparison of the BER as a function of the number of users between the three systems, OFDM-OCDMA- new ZCC, OFDM-OCDMA-FCC and SCM/OCDMA-FCC. At the received power (Psr = -20 dBm) and at an acceptable BER of $10^{-.T}$, it can be seen that there is an increase in our system represented by BER, which is degraded as the number of users.

The number of users found using SCM (subcarrier multiplexing)-OCDMA-FCC is 48 [4], while in our work, the number of users obtained with OFDM- OCDMA-New ZCC is 107. This result indicate that there is an improvement in the system performance (Cardinality), as there is an increase ss the number of users is calculated as follows:

$$\frac{107-48}{48}=120\%$$

A.O. Aldhaibani et al. [4] have found 100 users when using the OFDM-OCDMA-FCC. In this case, the cardinality compared to 48 for SCM/OCDMA-FCC is:

$$\frac{100-48}{48}=108\%,$$

The cardinality obtained by FCC code is enhanced in our work using the new ZCC by:

$$\frac{107-100}{100}=7\%$$

The OFDM-OCDMA- new ZCC can accommodate 107 users compared to 100 users of OFDM-OCDMA-FCC and 48 for SCM/OCDMA-FCC. In our code, we remark the rate of performance is increased in terms of number of user by 7% of OFDM-OCDMA-FCC and, also 120% of SCM/OCDMA-FCC. This improvement of capability for our system is due to the effect of the proposed new ZCC code, which can be constructed easily to provide a high number of simultaneous K users, and good correlation property.

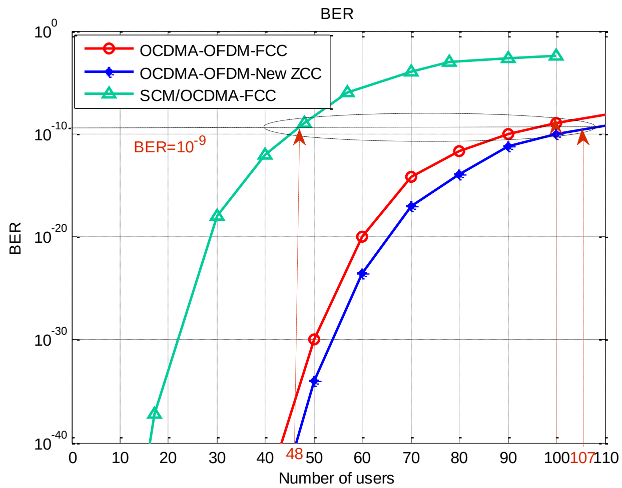

Figure 7: BER against number of users for ODCMA-OFDM systems using three codes (New ZCC) code,(SCM-FCC) code and (FCC) code with (W= 4).

VI. CONCLUSION

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

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