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A NEW MFCC CODE FOR SPECTRAL AMPLITUDE CODING OCDMA SYSTEM

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ABSTRACT

In this paper, we propose a new code design with one cross correlation for the Optical Code Division Multiple Access (OCDMA) system. The performance of the system with the proposed Modified FCC code is analyzed by taking into account the effect of shot noise, PIIN and thermal noise sources. From the numerical results, it is found that the Modified Flexible Cross Correlation code (MFCC) provides the best performance, in terms of the signal to noise ratio (SNR) and the bit error rate (BER), compared to MDW (Modified Double-Weight) and RD (Random diagonal) codes. Moreover, the simplicity in code construction and the flexibility in cross correlation control have made this code a compelling candidate for future Spectral Amplitude Coding Optical Code Division Multiple Access (SAC-OCDMA) applications.

Keywords: modified FCC code, BER, SNR.

INTRODUCTION

For the densification of data traffic on telecommunications networks, multiple access techniques, such as the Frequency Division Multiple Access (FDMA) and the Time Division Multiple Access (TDMA), have been developed. These multiplexing methods are used in the RF transmissions as well as in the optical communication systems. The wavelength division multiplexing (WDM) represents a transposition of FDMA in optical networks. The Multiple Access Code Division or CDMA is a multiplexing scheme defined as spread spectrum (Glisic and Vucetic, 1997). This technique was originally intended for military applications. It allows, by the spreading of the power over a wide channel frequency band, better resistance to the fading phenomena and gives the transmitted signal the form of a noise, making it difficult to detect by receivers whom the message is not intended.

Several studies related to the transposition of CDMA techniques in optical communication systems date from the last twenty years. Taking the advantage of the high bandwidth available in the optical channel, the Optical Code Division Multiple Access OCDMA also aims to increase the multiplexing capacity by increasing the number of users at the cost of the deterioration in the quality of the link (Prucnal, Santoro and Ting, 1986), (Maric, Kostic, Titlebaum, 1993). It is possible to distinguish two optical approaches the OCDMA; coherent and incoherent approach. In the incherent OCDMA system, Multiple Access Interference (MAI) is one of the main limitations due to the use of the unipolar codes. To reduce the MAI (Anuar and Aljunid, 2009), several techniques are proposed to eliminate the contribution of undesirable users. The Spectral Amplitude Coding Optical Code Division Multiple Access (SAC-OCDMA) is giving a best solution to reduce the effect of MAI by utilized code with flexible cross-correlation (Wei, Shalaby and Ghafouri, 2001).

Many investigations have been reported in order to develop new codes for SAC-OCDMA system such as; Optical Orthogonal codes 'OOCs' (Weng and We, 2001), Prime codes (Anuar and all., 2006), Modified Frequency-Hopping 'MFH' codes (Anuar and Aljunid, 2007), Double-Weight 'DW' code (Wei and Ghafouri, 2002), Modified Double-Weight 'MDW' code (Aljunid and all., 2005), Random diagonal 'RD' code (Hilal and all., 2009) and Flexible Cross Correlation 'FCC' code (Rashidi and all., 2013). However, these codes suffer from various limitations such as; the complication of construction, the poor cross correlation, and the code length is too long.

In this paper, we propose a new family code for SAC-OCDMA system. Since the concept code is based on the Flexible Cross Correlation (FCC) one, it is called Modified Flexible Cross Correlation (MFCC). This paper is organized as follows; the proposed code design and analysis are described respectively in the second and third section. Results and discussions are included in section four. Finally, a conclusion of this work is provided in the last section.

CODE DESIGN

Mathematical preliminaries

Optical codes are family of K (K for users) binary [0, 1] sequences of length, N, maximum cross correlation, λ_{max} and weight w. the optimum code set is one having minimum cross-correlation properties to support the maximum number of users with minimum code length (Anuar and all., 2006). This ensures guaranteed quality of services with least error probabilities for given number of users at least for short haul optical networking. It shows that, major bottleneck in the successful implementation of all optical networks is basically MAI when all the users try to transmit their data simultaneously. It can be conquered by designing coding sequences such that they may cause least overlapping between data chips (Kavehrad and Zaccarin, 1995).

Let A={a_n} and B={b_n} be the sequences of length such that:

$$\left.\begin{array}{ll}\{a_i\} = '0' \quad or \quad '1'. & i = 0,\ldots\ldots, N-1 \\ \{b_i\} = '0' \quad or \quad '1'. & i = 0,\ldots, N-1\end{array}\right\} \quad (1)$$

The auto and cross correlation functions of these sequences are defined, respectively, by;

$$\lambda_a(\tau) = \sum_{n=0}^{N-1} a_i a_{i+\tau} \quad (2)$$

$$\lambda_{ab}(\tau) = \sum_{n=0}^{N-1} a_i b_{i+\tau} \quad (3)$$

Since a_n is a {0, 1} binary sequence, the maximum value of λ_a (τ) in Equation (2) is for τ=0 and is equal to w, the weight of the sequence. Thus,

$$\lambda_a(0) = w \quad (4)$$

If λ_{xm} and λ_{xym} denote the maximum out of phase auto and cross-correlation values respectively, then an optical code of length 'N' and code weight 'W' can be written as (N, W, λ_{xm}, λ_{xym}) or λ_{max}= max {λ_{xm}, λ_{xym} } . It may also be noted that for an optical code a_n with code weight 'W' for auto- correlation can be written as follows;

$$\lambda_{a \ \max} = \sum_{n=0}^{N-1} a_i a_i = w \quad (5)$$

In practice for K users, it is required to have K number of codes in a set for given values of N, W, λ_{am} and λ_{abm}. The codes described by Equation (1) can also be represented in vector form as:

$$\left.\begin{array}{ll}A = \{a_i\} \quad for & i = 0,\ldots\ldots, N-1 \\ B = \{b_i\} \quad for & i = 0,\ldots, N-1\end{array}\right\} \quad (6)$$

Where A and B are vectors of length 'N' with elements as defined by Equation (6). In term of the vectors A and B, Equation (2) and Equation (3) are written as,

$$\lambda_A(0) = AA^T = w \quad (7)$$

Code construction

The concept of the Modified Flexible Cross Correlation (MFCC) is designed using three parameters; *N*, *w*, and λ_c witch represent respectively the code length, the code weight (the number of "1" in each codeword) and the cross correlation property of the proposed MFCC code.The new proposed optical MFCC code is represented in a matrix *K*×*N* where *K* rows represent the number of users and *N* columns represent minimum code length. It consists of two sub matrixes *A* and *B*, as follows:

$$MFCC = [A||B]_{K\times N} \quad (8)$$

Some properties are noted during the construction our proposed code, including:

- The first sub matrix *A* is designed such that the cross correlation (λ_c) between two consecutive codes is equal to 0. While the B matrix is designed with λ_c=1.
- The length of *A* matrix must be equal to *K*, where *K* represents the number of users. While the length of *B* matrix must be equal to *K+1*. Thus the total length of MFCC code is equal to;

$$N = 2(K-1) + w \quad (9)$$

- Autocorrelation and cross correlation property of MFCC can be written as:

$$\sum_{i=1}^{N} C_k(i) C_l(i) = \begin{cases} w; & k = l \\ 1 \ ; & k \neq l \end{cases} \quad (10)$$

When $C_k(i)$ represents the i^{th} component of the K^{th} MFCC code.

Using the above-mentioned properties MFCC code for three users can be written as:

$$MFCC = \begin{bmatrix} 1 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 1 \end{bmatrix} \quad (11)$$

In this case *K=3* and *N=7* for *w=3*.
The code word for each user according to (11) becomes:

$$MFCC = \begin{cases} User1; & \lambda_1, \lambda_4, \lambda_5 \\ User2; & \lambda_2, \lambda_5, \lambda_6 \\ User3; & \lambda_3, \lambda_6, \lambda_7 \end{cases} \quad (12)$$

NUMERICAL PERFORMANCES ANALYSIS

To evaluate the performances of the proposed MFCC code, the signal to noise ratio (SNR) and the bit error rate (BER) must be calculated using the following equations:

$$SNR = I^2 / \sigma^2 \quad (13)$$

Where *I* represents the incident current, expressed as:

$$I = \Re \int_0^\infty G(\upsilon) d\upsilon \quad (14)$$

And σ^2 is the the noise variance, witch is the sum of the powers of shot, PIIN (phase induced intensity noise) and thermal noise σ:

$$\sigma^2 = I^2_{shot} + I^2_{PIIN} + I^2_{thermal} \quad (15)$$

From equation (14), the $\Re$ represents the the PIN photodiode responsively.

In addition, the power spectral density is given from the reference (Abd and all., 2012), by:

$$G(\upsilon)=\sum_{k=1}^{k} d_k \begin{pmatrix} \sum_{i=1}^{N} C_k(i)C_l(i) \\ -\sum_{i=1}^{N} C_k(i)(C_k(i)C_l(i)) \end{pmatrix} \left\{ u\frac{\Delta\upsilon}{N} \right\} \quad (16)$$

Where,

$$\sum_{i=1}^{N} C_k(i)C_l(i)=\begin{cases} W; & k=l \\ 1; & k\neq l \end{cases} \quad (17)$$

$$\sum_{i=1}^{N} C_k(i)(C_k(i)C_l(i))=\begin{cases} 1; & k=l \\ 1; & k\neq l \end{cases} \quad (18)$$

$$\sum_{i=1}^{N} C_k(i)C_l(i)-\sum_{i=1}^{N} C_k(i)(C_k(i)C_l(i))= \begin{cases} W-1; & k=l \\ 0; & k\neq l \end{cases} \quad (19)$$

From (14) to (17) equations, the incident current becomes;

$$I=\Re\frac{p_{sr}}{\Delta\upsilon}(W-1) \quad (20)$$

and the noise powers are given as follows;

$$I_{shot}^2=2eBI=2eB\Re\int_0^\infty G(\upsilon)d\upsilon \quad (21)$$

$$I_{shot}^2=2eB\Re\frac{p_{sr}}{\Delta\upsilon}(W+3) \quad (22)$$

$$I_{PIIN}^2=BI^2\tau_c=B\int_0^\infty G(\upsilon)^2 d\upsilon \quad (23)$$

$$I_{PIIN}^2=\frac{B\Re^2 P_{sr}^2 KW}{N^2\Delta\nu}(W+3) \quad (24)$$

and

$$I_{thermal}^2=\frac{4K_bT_nB_r}{R_L} \quad (25)$$

From the above equations the SNR can be written as fllows;

$$SNR=\frac{\left(\frac{\Re P_{sr}(W-1)}{N}\right)^2}{\left[\frac{2eB_r\Re P_{sr}}{N}(W+3)+\frac{B\Re^2P_{sr}^2KW}{N^2\Delta\nu}(W+3)+\frac{4K_bT_nB_r}{R_L}\right]} \quad (26)$$

All parameters of the equations (26) are described in the Table-1.

Table-1. Parameters descriptions.

Parameter	Description
e	Electron charge
B	Noise equivalent of electrical bandwidth
K_b	Boltzmann constant
T_n	Absolute temperature
R_L	Load resistance

The Bit error rate is given using the SNR by;

$$BER=\frac{1}{2}erfc\left(\sqrt{\frac{SNR}{8}}\right) \quad (27)$$

RESULTS AND DISCUSSION

The system performance is analyzed using parameters listed in Table-2, and the numerical results are shown in Figures-1-3.

In order to compare the performance of our code to the existed codes, we have plotted the Bit Error Rate (BER) against the number of users for our code and two another codes; MDW code and RD code with weight *W= 4*, as illustrated in Figure-1. Form this Figure, it can be seen that our code provides improved performance compared with MDW and RD codes, with low BER (less than 10^{-9}).

Table-2. Parameters used in numerical calculation.

PD quantum efficiency	η = 0.75
Spectral width of broadband light source	$\Delta\lambda$ = 30nm ($\Delta\lambda$ = 3.75 THz)
Operating wavelength	λ_o = 1550nm
Electrical bandwidth	B = 155 MHz
Data transmission rate	R_b= 622 Mbps
Receiver noise temperature	T_n= 300K
Receiver load resistor	R_L= 1030Ω
Boltzmann's constant	K_b = 1.38 ×10^{-23} W/K/Hz
Electron charge	e = 1.60217646 × 10^{-19} coulombs
Light velocity	C = 3 ×10^8 m/s

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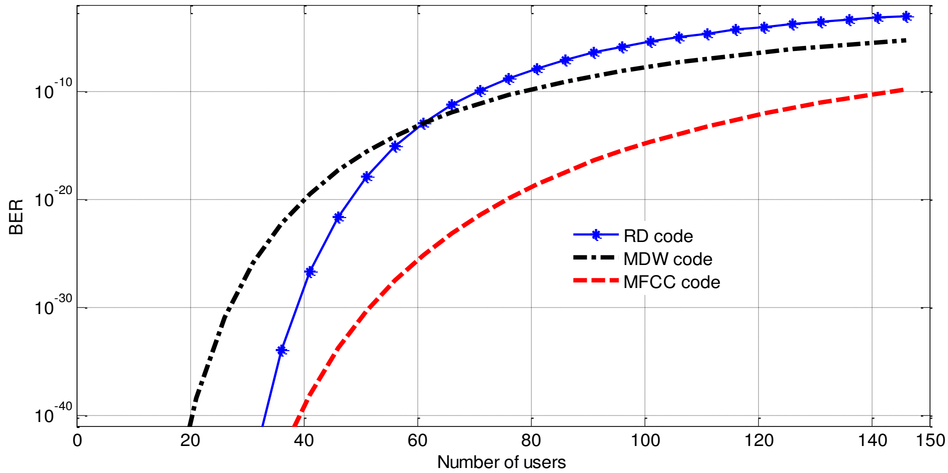

Figure-1. BER versus number of users for MFCC, MDW and RD codes.

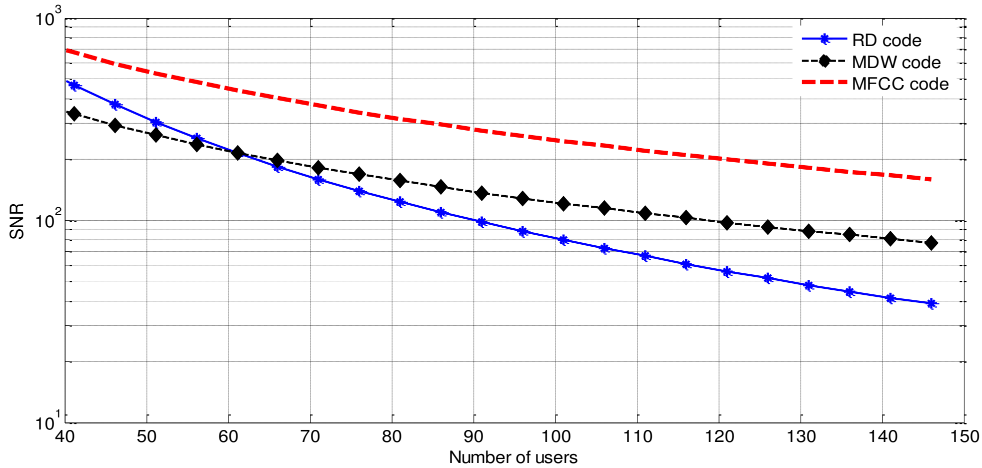

Figure-2. SNR versus number of users for MFCC, MDW and RD codes.

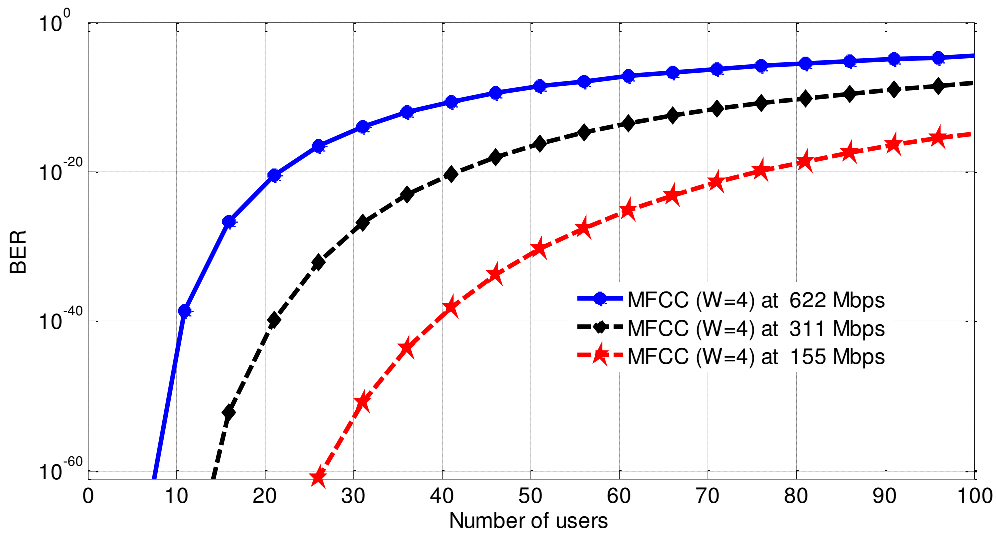

Figure-3. BER versus number of users for MFCC code with different data transmission rate.

Figure-2, presents a comparison of the performance of MFCC code with the MDW and RD codes in term of the variation of the signal to noise ratio (SNR) and the number of users, it can be stated that the proposed code MFCC exhibits significantly better performance (high SNR) compare to other codes,. This ensuring a good quality of data transmission.

Finally, the effect of the data transmission rate in the performance of the proposed MFCC code are analyzed, by plotting the BER for different value of the R_b, as illustrated in Figure-3. From these curves, it is conclude the increasing of the data transmission rate and it is degradation on the performance system.

CONCLUSIONS

A new Modified Flexible Cross Correlation (MFCC) code has been studied and proposed for Optical Code Division Multiple Access OCDMA system. The analysis is done by calculating the signal to noise ratio (SNR) and the bit error rate (BER), taking into account the effect of shot noise, PIIN and thermal noise sources. In order to evaluate the performance of the proposed code, the numerical results obtained from the implementation of this code are compared with those of two other codes; MDW and RD codes. From this comparison, it is found that the MFCC code is the best in terms of BER compared to MDW and RD codes. In addition, the simplicity in code construction and flexibility in cross correlation control has made this code a compelling candidate for future OCDMA applications.

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