New Approach of Flexible Cross Correlation (FCC) Algorithm for Noise Alleviation on OCDMA Systems

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Abstract **—The flexible cross correlation (FCC) code algorithm for optical code division multiple access (OCDMA) systems has been developed. The FCC approach has advantages, such as flexible cross-correlation property at any given number of users and weights, as well as effectively suppressed the impact of phase-induced intensity noise (PIIN) and multiple-access interference (MAI) cancellation property. The results revealed that the FCC code can accommodate 150 users, where FCC code offers 66%, 172%, 650% and 900% improvement as a contrast to 90, 55, 20 and 15 numbers of users for Dynamic Cyclic Shift (DCS), Modified Double Weight (MDW), Modified Frequency Hopping (MFH) and Hadamard codes respectively, for a permissible bit error rate (BER) of 10^{-9}.**

Keywords—FCC Code; Correlation Properties; MAI; OCDMA Systems.

I. INTRODUCTION

The higher the cross-correlation between any two code words will produce stronger impact of the MAI and erroneous decisions which will degrade the system performance of BER [1]. Therefore, the correlation properties of the code address play a significant part in the performances of OCDMA systems. Furthermore, when it involves the correlation properties it also noticed issues of the code size and the code length. The code length has a limitation to the number of simultaneous users that the OCDMA systems can accommodate [2]. Since, the OCDMA system performance depends on the address code then the technique to adapt in OCDMA system must have big capacity and good correlation [3-4]. Most address codes have been proposed for the OCDMA to overwhelm the impact of correlation properties such as DCS, MFH, MDW and Hadamard codes, respectively [5-8]. However, these address codes have several limitations such as the code construction is complicated (e.g. MFH code) and fixed an even natural number for MDW code. In this paper, a new coding algorithm called FCC code is proposed to improve system capacity and achieve higher performance possible through suppressing PIIN and eliminating MAI. The proposed code also has an advantage of high cardinality and low received power with shorter code length.

II. ALGORITHM OF FCC CODE

In OCDMA network to allow receivers to distinguish each of the possible users, to reduce channel interference and to accommodate large number of users, optical codes should have large values of W and the size K.

Step 1:

We set an optical code consists of code length N, weight W, cross-correlation λ_{max} and for users K, (N, W, λ_{max}). This set of codes is then represented by $K\times N$ code matrix where, it can be expressed by equation (1);

$$A_K^W = \begin{bmatrix} a_{11} & a_{12} & a_{13} & 0 & 0 & \cdots & 0 \\ a_{21} & a_{22} & a_{23} & a_{24} & 0 & \cdots & \vdots \\ 0 & a_{32} & a_{33} & a_{34} & a_{35} & 0 & \vdots \\ 0 & 0 & a_{43} & a_{44} & a_{45} & a_{46} & \vdots \\ \vdots & \ddots & \ddots & \ddots & \ddots & \ddots & \vdots \\ 0 & 0 & \cdots & \cdots & \cdots & \cdots & a_{KN} \end{bmatrix} = \begin{bmatrix} A_1 \\ A_2 \\ A_3 \\ \vdots \\ \vdots \\ A_K \end{bmatrix} \quad (1)$$

where,

$$A_1 = a_{11}, a_{12}, a_{13} ... a_{1N}$$
$$A_2 = a_{21}, a_{22}, a_{23,} a_{24} ... c_{2N}$$
$$A_3 = a_{31}, a_{32}, a_{33,} a_{34} ... c_{3N}$$
$$\vdots$$
$$A_K = a_{K1}, a_{K2}, a_{K3} ... a_{KN}$$

The $K\times N$ code matrix A_K^W is called the **Tridiagonal Code Matrix,** whose elements a_{ij} of $K\times N$ code matrix A_K^W is the binary sequence [0, 1] and can be written as;

$$A_K^W = a_{ij} = 0\, or\, 1\ for\ {}_{j=1,2,...N}^{i=1,2,...K} \quad (2)$$

The rows of A_1, A_2 and A_k represent the K codeword and it is assumed that, the code weight of each of the K codeword is to be W.

Step 2:

The K codes represented by the K rows of the $K\times N$ code matrix in Equation (1) is to represent a valid set of K

codeword with in phase cross-correlations λ_{max} and code weight W; it must satisfy the following conditions;

1. The code weight of each codeword should be equal to W where,

$$\sum_{j=1}^{N} a_{ij} = W, \; i = 1,2...K \tag{3}$$

2. The in phase cross-correlation λ_{max}, between any of the K code words (K rows of the matrix, A_K^W) should not exceed code weight W. That is,

$$X_i X_j^T = \begin{cases} \leq \lambda_{max} & for\ i \neq j \\ = W & for\ i = j \end{cases} \tag{4}$$

3. From equation (4), it is seen that the $W = X_i X_i^T$ is the in-phase auto-correlation function of codes. $X_i\ Y_j^T$ is the out of phase cross-correlation between the i^{th} and the j^{th} codes. It follows that $X_i X_i^T$ should be greater than $X_i\ Y_j^T$. In other words, $W > \lambda_{max}$

4. All K rows of A_K^W should be linearly independent because each codeword must be uniquely different from other words. That is to say the rank of the $K \times N$ code matrix A_K^W should be K. Moreover, for A_K^W to have rank K, thus, it can be written as $N \geq K$

Step 3:

From the four conditions above in **Step 2**, one of the matrices binary sequences as shown in equation (1) in **Step 1**, whose the first i^{th} row for the first K user is given by;

$$A_i = \overbrace{0...0}^{r(i-1)} \; \overbrace{11..1}^{W} \; \overbrace{0...0}^{r(K-i)} \tag{5}$$

The N of the codes which is the length of the rows of the $K \times N$ code matrix A_K^W is given by;

$$N = WK - \lambda_{max}(K-1) \tag{6}$$

It can be seen that the N is minimum under the assumed conditions. Table 1 shows the FCC code for a given K=3, W=2 and $\lambda_{max} \leq 1$.

Table 1: Codewords of FCC Code for K=3, W=2 and $\lambda_{max} \leq 1$.

Users \ Wavelength	λ_1=1550.0	λ_2=1550.8	λ_3=1551.6	λ_4=1552.4
User 1	1	1	0	0
User 2	0	1	1	0
User 3	0	0	1	1

III. FCC ENCODER-DECODER DESIGN

The FCC OCDMA encoder-decoder have been designed using simulation software called *OptiSystem* software from *Optiwave*™. The encoder designs utilizing one single broadband source being sliced for three channels with code weight equal to two. An evasion interference subtraction is used as the detection scheme at the receiver. Fig. 1 shows the encoder design utilizing the FCC code sequence offers simplicity and cost-effectiveness using the LED as a light source, Mach-Zehnder as an external modulator, WDM Mux-Demux acting as wavelength combiner as well as code spectrum slicing also with the Non-Return Zero modulation format and Pseudo Random Bit Sequences (PRBS), respectively.

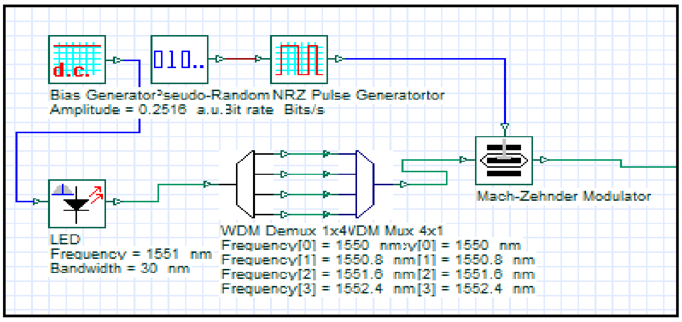

Fig.1 FCC Code Encoder Design

Fig. 2 shows the FCC decoder design utilizing fiber Bragg grating (FBG) which will decode the receiving signal from an optical fiber. A single FBG will encode two wavelengths represented by λ_2, λ_3, and λ_3, λ_4 which are correlated or overlapping wavelength as shown in Table 1. Due to that, FBG bandwidth will have a spectral width of 1.6nm for correlated wavelength and 0.8nm for uncorrelated wavelength such as λ_1 and λ_4 for both wavelengths. This design will reduce much bandwidth allocated for the code that has been selected for OCDMA system transmissions.

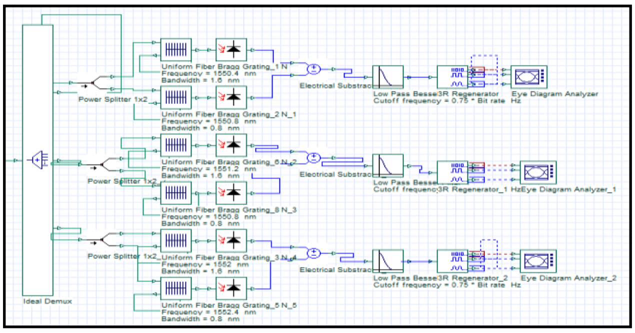

Fig. 2: FCC Code Decoder Design

IV. PERFORMANCE ANALYSIS AND RESULTS

In [10], we elaborate details the derivation of numerical expression for the Signal-To-Noise Ratio (SNR) with the presence of noise such as shot noise, intensity noise and thermal noise respectively for the FCC code. The SNR and bit error rate (BER) for the FCC code are defined by the numerical expression as follows;

$$SNR = \frac{\left[\frac{\Re P_{sr} W}{N}\right]^2}{\left[\frac{2eB\Re P_{sr}}{N}\right][W+3] + B\Re^2\left[\frac{P_{sr}{}^2 KW}{N^2 \Delta V}\right][W+3] + \frac{4K_b T_n B}{R_L}} \tag{7}$$

Since, there is no pulses or data send for bit ‘0’and assuming that the noise distribution is Gaussian, thus the BER can be obtained as follows [9];

$$BER = 0.5\,erfc\left(\sqrt{\frac{SNR}{8}}\right) \tag{8}$$

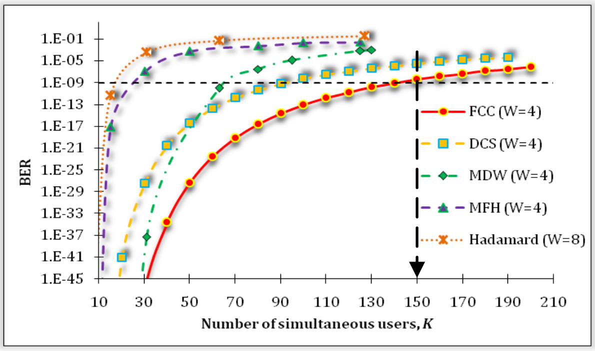

Fig. 3: Number of simultaneous users versus system performance BER for various OCDMA codes.

It can be seen that, the system performance BER degrade as the number of simultaneous users increased. At system performance BER of 10^{-9}, the FCC code can accommodate 150 numbers of simultaneous users, which is the highest number of users as compared to 90, 55, 20 and 15 for DCS, MDW, MFH and Hadamard codes, respectively. The percentage of the number of simultaneous users improvements are 66 %, 172 %, 650 % and 900 % as a contrast to DCS, MDW, MFH and Hadamard codes, respectively. From this fact, the FCC code had indicated good performance due to arrangement of code algorithm and flexibility cross-correlation function.

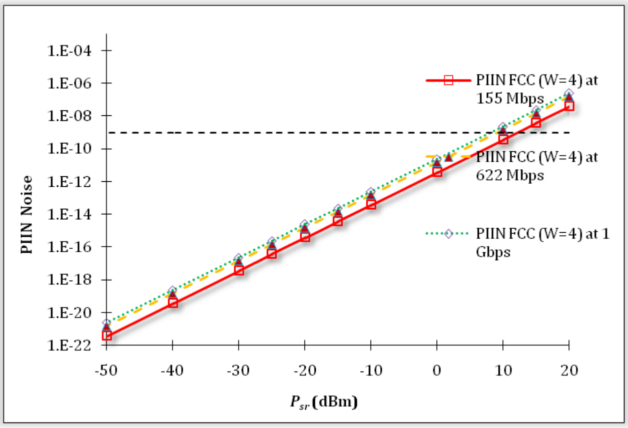

Fig. 4: Performance of effective received power versus PIIN noise for FCC code (W=4) at different bit rates 155 Mbps, 622 Mbps and 1 Gbps.

Fig. 4 illustrates the curves of effective received power P_{sr} versus PIIN noise at bit rates of 155 Mbps, 622 Mbps and 1 Gbps for FCC code (W=4). The values of P_{sr} are varied from - 50 dBm to 20 dBm. It can be seen that, the linear curves show an increase in PIIN noise as the bit rate increases. The low bit rate of 155 Mbps, maximally suppressing the effects of PIIN noise. The magnitude of PIIN noise is eliminated by a factor of 1.0 where 1×10^{-13}, 1×10^{-13} and 1×10^{-14} as values of bit rates decreases from 1 Gbps to 155 Mbps at P_{sr} = - 10 dBm. The FCC (W=4) coding system performance degradation as the bit rate increases which will introduce to higher noise effects.

V. CONCLUSIONS

The algorithm of the FCC code to enhance the impact of correlation has been presented. The FCC code had shown good performance indicated that FCC OCDMA coding system can accommodate a high number of active users equal to 150 at permissible BER of 10^{-9}. We can ascertain from these results that, this will give an opportunity in OCDMA system for better quality of service in optical access networks for future generation’s usage.

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