Alleviation Noise Effect Using Flexible Cross Correlation Code in Spectral Amplitude Coding Optical Code Division Multiple Access Systems

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***Abstract*--- A new code for Spectral Amplitude Coding - Optical Code Division Multiple Access (SAC-OCDMA) is proposed and is called Flexible Cross-correlation (FCC) code. The FCC code possesses various advantages; including easy code construction using Tridiagonal matrix compared to other SAC-OCDMA codes such as MDW, MQC and MFH, shorter code length and the important properties of this code is the flexible cross-correlation. Our results reveal that FCC code can effectively alleviated Phase Induced Intensity Noise (PIIN) and allows large cardinality and improve the bit error rate performance.**

***Keywords:* Flexible Cross-correlation (FCC) Code, Phase Induced Intensity Noise, SAC-OCDMA, Tridiagonal Matrix**

I. INTRODUCTION

Optical code division multiple access (OCDMA) is one class of system that has the advantages of being able to provide each user asynchronous access to the network, without strict wavelength controls [1]. OCDMA system has been recognized as one of the most important technologies for supporting many users in shared media simultaneously and in some cases can increase the transmission capacity of an optical fiber [2]. The use of single-mode optical fiber in high bit-rate long-haul communication links has become common due to the low propagation loss and the large bandwidth available. The development of local area networks (LAN's) using optical fiber is rapidly continuing [3]. In OCDMA system, each user transmits an assigned code whenever a bit of "1" is to be transmitted and does not transmit anything whenever a bit of "0" is to be transmitted. In OCDMA, the most important consideration is the code design; improperly code designed and higher number of simultaneous users can be seriously degraded the system performance due to existing of Multi User Interference (MUI) [4]. MUI is the interference from other users transmitting at the same time which will limit the effective error probability with the presence of noise for the overall system. PIIN is deeply related to MUI due to overlapping spectra from different users [5]. PIIN depends on the number of interfering users and cannot be improved by increasing the transmitted power [6]. One of the effective solutions for alleviating the PIIN is decreasing the number of interferences between the incoherent source signals of different users. Most codes have been proposed in OCDMA systems such as Modified Frequency Hopping (MFH), Modified Quadratic Congruence (MQC) and Modified Double Weight (MDW) [7-9] codes. However, these codes have several limitations such as the code is either too long (e.g. Optical Orthogonal Code and Prime Code), construction is complicated (e.g. MFH code), or poorer cross-correlation (e.g. Hadamard) and fixed an even natural number for Modified Double Weight (MDW) code. Finally, the longer code length had limited the flexibility of the codes since it will require wide bandwidth source (e.g. Prime code).

In this paper, a new code called the Flexible Cross-correlation (FCC) code has been developed. It has been assumed that the in phase cross-correlation value can be flexible which ensures that each codeword can be easily distinguished from every other address sequence. The code is optimum in the sense that the code length is shorter for a given in phase cross-correlation function. The FCC code can be constructed with simple Tridiagonal matrix property, given any number of users and weights. Finally, we analyze the proposed code with our theoretical analysis and intensive simulations. It has been shown that, with the structure of the proposed code can effectively alleviate the PIIN and hence improved the bit error rate (BER) performance.

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II. ESSENTIAL OF OPTICAL CDMA CODE.

Optical codes are family of K (for K users) binary [0, 1] sequences of length N, hamming- weight *W* (the number of "1" in each codeword) and the maximum cross-correlation, λmax. The optimum code set is one having any desired cross-correlation properties to support the maximum number of users with minimum code length. This ensures guaranteed quality of services with least error probabilities for giving number of users K at least for the short haul optical networking [6].

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

$$\left.\begin{aligned}\{a_n\} &= '0'\ or\ '1',\ i = 0,...N-1\\ \{b_n\} &= '0'\ or\ '1',\ i = 0,...N-1\end{aligned}\right\} \quad (1)$$

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

$$\lambda_x(\tau) = \sum_{N=0}^{N-1} x_i x_{i+\tau} \quad (2)$$

$$\lambda_{xy}(\tau) = \sum_{N=0}^{N-1} x_i y_{i+\tau} \quad (3)$$

Since a_n is a {0, 1} binary sequence, the maximum value of $\lambda_x(\tau)$ in Equation (2) is for τ = 0and is equal to *W*, the hamming- weight of the sequence can be expressed as:

$$\lambda_x(0) = W \quad (4)$$

If λ_{xm} & λ_{xym} denote the maximum out of phase auto correlation and cross-correlation values respectively, then an optical code of length N and hamming- weight *W* can be written as (N,*W*, $\lambda_{xm,}$ λ_{xym}). A (N, *W*, $\lambda_{xm,}$ λ_{xym})- FCC is called the constant- weight symmetric when λ_x =, λ_{xy}= $\lambda_{max,}$. We used the shorthand notation of (N, *W*, λ_{max}) and a Φ (N, *W*, λ_{max}) for the largest possible cardinality. It may also be noted that for an optical code a_n with hamming- weight '*W*' for auto correlation can be written as follows:

$$\lambda_{x\max} = \lambda_x(0) = \sum_{N=0}^{N-1} x_i x_i = W \quad (5)$$

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

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

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,

$$\lambda_{A(0)} = AA^T = W \quad (7)$$

$$\lambda_{AB(0)} = AB^T$$

Where A^T and B^T denote the transpose of vectors A and B, respectively.

III. FLEXIBLE CROSS-CORRELATION (FCC) CODE DEVELOPMENT.

Step 1: We consider a set of K, cross- correlation $\lambda_{max,}$ length of code N and hamming-weight *W* for K users. This set of codes is then represented by a KxN matrix A_K^w where the elements a_{ij} of A_K^w is binary [0, 1] can be written as:

$$A_K^W = \left\{ a_{ij} = '0'\ or\ '1'\ for\ \begin{matrix} i = 1,2,..K \\ j = 1,2,..N \end{matrix} \right\} \quad (8)$$

The matrix A_K^w is here called the **Tridiagonal Code Matrix**. Since the K codes represented by the K rows of the code matrix are unique and independent of each other, A_K^w should have rank K. Moreover, for A_K^w to have rank K,

$$N > K \quad (9)$$

Step 2: The KxN optical code matrix A_K^w as defined by Equation (8). The hamming-weight of each of the K codes is assumed to be *W*. The Tridiagonal code matrix A_K^w is given by Equation (10) and the rows A_1, A_2, A_K represent the K code words.

$$A_K^w = \begin{bmatrix} a_{11} & b_{12} & c_{13} & 0 & \dots & 0 & 0 \\ 0 & d_{14} & a_{21} & b_{22} & \dots & 0 & 0 \\ 0 & 0 & c_{23} & d_{24} & \dots & 0 & 0 \\ \vdots & \ddots & \ddots & \ddots & \dots & 0 & 0 \\ 0 & 0 & 0 & 0 & \dots & c_{i-1} & a_{KN} \end{bmatrix} = \begin{bmatrix} A_1 \\ A_2 \\ \vdots \\ A_K \end{bmatrix} \quad (10)$$

where,

$$\begin{aligned} A_1 &= a_{11}, b_{12}, \dots d_{1N} \\ A_2 &= d_{14}, a_{21}, \dots b_{2N} \\ A_3 &= c_{23}, d_{24}, \dots a_{3N} \\ A_K &= 0,0, \dots c_{1-i}, a_{KN} \end{aligned}$$

Step 3: The K codes represented by the K rows of the code matrix A_K^w in Equation (10) are to represent a valid set of K codeword with in phase cross-correlations λ_{max} and hamming-weight *W*, it must satisfy the following conditions:

1. The elements {a_{ij}} of A_K^w must have values "0" or "1"

a_{ij} = "0" or "1" for i=1,2,..K, j=1, 2,..N (11)

2. The hamming-weight *W* of each codeword should be equal to *W* where,

$$\sum_{j=1}^{N} a_{ij} = W,\ i = 1,2...K \quad (12)$$

3. 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 hamming-weight W. That is

$$A_i A_j^T = \begin{cases} \le \lambda_{\max} & for\ i \ne j \\ = W & for\ i = j \end{cases} \tag{13}$$

4. From Equation (13), it is seen that the $W = A_i A_i^T$ is the in-phase auto- correlation function of codes. $A_i A_j^T$ is the out of phase correlation between the i[th] and the j[th] codes. It follows that $A_i A_i^T$ should be greater than $A_i A_j^T$. In other words,

$$w \ge \lambda_{\max} \tag{14}$$

5. 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 matrix A_K^W should be K.

One of the matrices that satisfies the four conditions above, is the KxN Matrix A_K^W whose i[th] row is given by,

$$A_i = \overbrace{0\ldots0}^{r(i-1)} \quad \overbrace{1\,1\ldots1}^{w} \quad \overbrace{0\ldots0}^{r(K-i)} \tag{15}$$

The length N of the codes which is the length of the rows of the matrix A_K^W is given by,

$$N = WK - \lambda_{\max}(K-1) \tag{16}$$

It can be seen that the length N is minimum under the assumed conditions.

<u>Step 4</u>: On the basis of the above discussions, the construction of an optical code having a value of K, hamming-weight W, λ_{max} consists of the following steps:

1). For a given number of users K, and hamming-weight W, forms a set of flexible in phase cross-correlation code with minimum length as given by Equation (15)
2). The length N of code matrix has defined by the Equation (16)
3). The K rows of the code matrix that give the K optical CDMA codes having flexible in phase cross correlation, hamming-weight W and minimum code length.

This procedure will now be explained with the help of an example:-

It is desired to generate a set of minimum length with flexible in phase cross-correlation optical code. Table 1 and Table 2 shows the FCC codeword for a given number of users, hamming- weight W and flexible cross-correlation λ_{max}.

Here K=4, W=3, the tridiagonal code matrix for this code is

$$A_4^3 = \begin{bmatrix} 1&1&1&0&0&0&0&0&0 \\ 0&0&1&1&1&0&0&0&0 \\ 0&0&0&0&1&1&1&0&0 \\ 0&0&0&0&0&0&1&1&1 \end{bmatrix}_{4x9}$$

TABLE 1
THE FCC CODE WITH FLEXIBLE, K = 8, W = 3 and N=9.

Active Users	Codeword								
K_1	1	1	1	0	0	0	0	0	0
K_2	0	0	1	1	1	0	0	0	0
K_3	0	0	0	0	1	1	1	0	0
K_4	0	0	0	0	0	0	1	1	1

λmax=1

λmax=0

Similarly for tridiagonal code matrix, for K = 8, W = 3, for this code is,

$$A_8^3 = \begin{bmatrix} 1&1&1&0&0&0&0&0&0&0 \\ 0&1&1&1&0&0&0&0&0&0 \\ 0&0&1&1&1&0&0&0&0&0 \\ 0&0&0&1&1&1&0&0&0&0 \\ 0&0&0&0&1&1&1&0&0&0 \\ 0&0&0&0&0&1&1&1&0&0 \\ 0&0&0&0&0&0&1&1&1&0 \\ 0&0&0&0&0&0&0&1&1&1 \end{bmatrix}_{8x10}$$

TABLE II
THE FCC CODE WITH FLEXIBLE K = 8, W = 3 and N=10.

Active Users	Codeword									
K_1	1	1	1	0	0	0	0	0	0	0
K_2	0	1	1	1	0	0	0	0	0	0
K_3	0	0	1	1	1	0	0	0	0	0
K_4	0	0	0	1	1	1	0	0	0	0
K_5	0	0	0	0	1	1	1	0	0	0
K_6	0	0	0	0	0	1	1	1	0	0
K_7	0	0	0	0	0	0	1	1	1	0
K_8	0	0	0	0	0	0	0	1	1	1

λmax=0

IV. SYSTEM PERFORMANCE ANALYSIS.

The effect of the presence of noise in our analyses considered only shot noise $\langle i_{shot} \rangle$, incoherent intensity noise $\langle i_{PIIN} \rangle$ and thermal noise $\langle i_{thermal} \rangle$ to evaluate the system performance. The proposed system is based on the NAND subtraction detection [10] with Fiber Bragg Grating (FBG) followed by a photo - detector. Signal to Noise Ratio (SNR) is calculated at the receiver side and only one photodiode accommodated for each user and *I* is denoted as the current flow through the photodiode. The SNR is defined as the average signal to noise power, $SNR = \left[I^2 / \sigma^2 \right]$, where σ^2 is the average power of noise which is given by;

$$\sigma^2 = \langle i_{shot}^2 \rangle + \langle i_{PIIN}^2 \rangle + \langle i_{thermal}^2 \rangle \quad (17)$$

Equation (17) can be expressed as;

$$\sigma^2 = 2eBI + I^2 B\tau_C + \frac{4K_b T_n B}{R_L} \quad (18)$$

where, e is the electron charge, I is the average photocurrent, I^2 is the power spectral density for I, B is the noise equivalent of electrical bandwidth, K_b is the Boltzmann constant, T_n is the *a*bsolute receiver noise temperature and R_L is the receiver load resistor.

From Equation (17) it has been assumed that the optical bandwidth is much larger than the maximum electrical bandwidth. The first term, second and third from Equation (18) can be denoted as the shot noise component, an intensity noise and the thermal noise respectively. Noticed, the effect of receiver's dark current has been neglected in this proposed system analysis. The total effect of intensity noise and shot noise follows the negative binomial distribution [12]. The broadband pulse coming thru to the FBG as an incoherent light field is mixed and incident upon a photo-detector while the phase noise of the fields causes an intensity noise in term of the photo-detector output. The source coherence time τ_c is given as [10]:

$$\tau_c = \frac{\int_0^\infty G^2(v)\,dv}{\left[\int_0^\infty G(v)\,dv \right]^2}, \quad (19)$$

where, $G(v)$ denotes as the single sideband source power of spectral density (PSD).

We consider the A_K^W in Equation (10) as an KxN Code Matrix of flexible cross-correlation optical codes family as mentioned is **Section 2.** The autocorrelation of each codeword $X_{ij} = x_1, x_2, x_3 .. x_N)$ and the cross-correlation between any two distinct codeword $X_{ij} = x_1, x_2, x_3 .. x_N)$ and $Y_{ij} = y_1, y_2, y_3 .. y_N)$ are satisfy the following condition [5]:

$$\lambda_x(\tau) = \sum_{i=1}^{N} x_i x_{i+\tau} = W \quad \text{for } \tau = 0 \quad (20)$$

$$\lambda_{xy}(\tau) = \sum_{i=1}^{N} x_i y_{i+\tau} = 0 \quad \text{for } \tau = 0 \quad (21)$$

Hence, according to the properties of FCC code described in **Section 3,** the X_{ij} and Y_{ij} denoted the *i*th element of the Kth row and *j*th elemnt of N column for Code Matrix A_K^W of FCC code sequences which can be written as:

$$\sum_{j=1}^{j} \sum_{i=1}^{K} X_{ij} Y_{ij} = \begin{cases} W, & For \quad i = j, \\ 1, & For \quad i \neq j \end{cases} \quad (22)$$

and

$$\sum_{j=1}^{j} \sum_{i=1}^{K} X_{ij} \bullet Y_{ij} = \begin{cases} W, & For \quad i = j \\ 1, & For \quad i \neq j \end{cases} \quad (23)$$

For NAND operation;

$$\sum_{j=1}^{j} \sum_{i=1}^{K} X_{ij} Y_{ij} \; (\overline{X_{ij} \bullet Y_{ij}}) = \begin{cases} 1, & For \quad i = j \\ 1, & For \quad i \neq j \end{cases} \quad (24)$$

Therefore, from Equation (24), the NAND operation of $X_{ij} Y_{ij}$ $(\overline{X_{ij} \bullet Y_{ij}})$ is valid for i≠j. Equation (22) shows the cross-correlation for $X_{ij} Y_{ij}$ is equal to one for i≠j. Thus, MUI can be fully relegated when the subtraction is valid for $X_{ij} Y_{ij}$ $(\overline{X_{ij} \bullet Y_{ij}})$ with $X_{ij} Y_{ij}$ when i≠j. Thus, the properties of subtraction can be expressed as follows:

$$\sum_{j=1}^{j} \sum_{i=1}^{K} X_{ij} Y_{ij} - \sum_{j=1}^{j} \sum_{i=1}^{K} X_{ij} Y_{ij} \; (\overline{X_{ij} \bullet Y_{ij}}) = \begin{cases} W-1, & For \quad i = j, \\ 0, & For \quad i \neq j, \end{cases} \quad (25)$$

The proposed system was analyzed with transmitter and receiver, we used the same assumption that used in [10] and those are important for mathematical preliminaries simplicity. Since, to analyze the proposed system, we assume the following assumptions:

- Each unpolarized source PSD and its spectrum is flat over the system bandwidth of $[v_{o} \pm \Delta v/2]$ with amplitude $P_{sr}/\Delta v$, v_o is the central optical frequency and Δv is the optical source bandwidth expressed in Hertz.
- Each user has equal power at receiver
- Each bit stream from each user is synchronized.

- Each power spectral component has an identical spectral width.

Based on the above assumptions, the proposed systems can easily analyze using the Gaussian approximation. The power spectral density of the received optical signals can be written as [10]:

$$G(v) = \frac{P_{sr}}{\Delta v} \sum_{K=1}^{K} d_K \sum_{j=1}^{j} \sum_{i=1}^{K} X_{ij} Y_{ij} [\Pi(i)], \tag{26}$$

where, P*sr* is the received power from a single source, Δv can be assumed as a perfect rectangular unit step function and can be illustrated in Figure. 1.

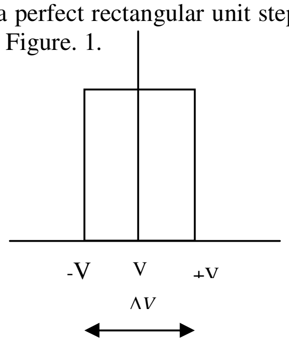

Figure 1: Bandwidth of ΔV

Here Π (*i*) is equal to;

$$\prod(i) = \left\{u\left[v - v_o - \tfrac{\Delta v}{2N}(-N+2i-2)\right] - u\left[v - v_o - \tfrac{\Delta v}{2N}(-N+2i)\right]\right\}$$

From Equation (26), the PSD of the system can be written as follows:

$$G(v) = G(v) = \frac{P_{sr}}{\Delta V} \sum_{k=1}^{K} d_k \sum_{j=1}^{j} \sum_{i=1}^{K} X_{ij} Y_{ij} \left\{u\left[v - v_o - \tfrac{\Delta v}{2N}(-N+2i-2)\right] - u\left[v - v_o - \tfrac{\Delta v}{2N}(-N+2i)\right]\right\} \tag{27}$$

where, the {0, 1} is an element of unit step function given as follows:

$$\left.\begin{matrix} 1, for \;\; v \ge 0 \\ 0, for \; v < 0 \end{matrix}\right\} \in \prod(i) \tag{28}$$

Thus, Equation (27) we can simplify as follows:

$$G(v) = \frac{P_{sr}}{\Delta V} \sum_{k=1}^{K} d_k \sum_{j=1}^{j} \sum_{i=1}^{K} X_{ij} Y_{ij} \left\{u[\frac{\Delta v}{N}]\right\} \tag{29}$$

d_K represents the binary data of the *K*th user that is “1” or “0” where d_K can be expressed as:

$$\left[\sum_{k=1}^{K} d_k\right] = \left[d_1 + d_2 + \ldots\ldots + d_{k-1} + d_k\right] \tag{30}$$

Only one PSD spectrum will be calculated, hence summation of d_k is equivalent to the number of hamming-weight *W*. Noticed, the photodiode current I can be written as follows:

$$I = \Re \int_0^\infty G(v)\, dv \tag{31}$$

$\Re$ represents as the responsivity of the photo-detectors and is given by $\Re = (\eta e)/(h v_c)$ where η is the quantum efficiency, ***e*** is the electron charge, *h* is the Planck’s constant, and v_c is the central frequency of the original broadband optical pulse [10]. By substituting Equation (29) into Equation (31), the photodiode current *I* can be written as follows:

$$I = \Re \int_0^\infty G(v) dv = \Re \int_0^\infty \frac{P_{sr}}{\Delta V} \left[\sum_{K=1}^{K} d_k\right] \left[\sum_{j=1}^{j} \sum_{i=1}^{K} X_{ij} Y_{ij} \left\{u[\frac{\Delta v}{N}]\right\}\right] dv \tag{32}$$

thus, after simplification, Equation (32) we can obtain as follows:

$$I = \Re \left[\frac{P_{sr}[W]}{N}\right] \tag{33}$$

The power of shot noise can be written as;

$$\langle i_{shot}^2 \rangle = 2eB(I_1 + I_2) = 2eB\Re\left[\int_0^\infty G_1(v)dv + \int_0^\infty G_2(v)dv\right]$$

$$= 2eB\Re\left[\frac{P_{sr}}{N} \sum_{k=1}^{K} d_k \sum_{j=1}^{j} \sum_{i=1}^{K} X_{ij} Y_{ij} + \frac{P_{sr}}{N} \sum_{k=1}^{K} d_k \sum_{j=1}^{j} \sum_{i=1}^{K} X_{ij} Y_{ij} \, (\overline{X_{ij} \bullet Y_{ij}})\right]$$

$$= 2eB\Re\left[\frac{PsrW}{N} + \frac{P_{sr}}{N} \sum_{K=1}^{K} dK + \frac{Psr}{N} + \frac{Psr}{N} \sum_{K=1}^{K} dK\right]$$

Thus, the average total noise power can be written as follows;

$$I_{shot} = 2eB\Re \cdot \left[\frac{Psr}{N}[3W+1]\right] \tag{34}$$

We assume that, the intensity noise will dominate the broadband sources. Hence, with power spectral density from each user is the same; therefore we calculate the receiver intensity noise directly from the total power spectral density of each photodiode. From Equation (18), the intensity noise at the receiver output is given by [10]:

$$\langle i_{PIIN}^2 \rangle = B(I_1^2 \tau_{C1} + I_2^2 \tau_{C2}) = I^2 * \tau_c * B \tag{35}$$

Where I_1 and I_2 are the average photodiode currents, τ_{c1} and τ_{c2} are the coherence times of the light incident on each photodiode as shown in Equation (19). From Equation (35), the power spectral density of I^2 can be described as follows:

$$\langle I_{PIIN}^2 \rangle = B\Re^2\left[\int_0^\infty G_1^2(v)dv + \int_0^\infty G_2^2(v)dv\right]$$

$$\langle I_{PIIN}{}^2 \rangle = \left[\Re^2\left[\int_0^\infty G(v)dv\right]^2\right] \times \frac{\int_0^\infty G^2(v)dv}{\left[\int_0^\infty G(v)dv\right]^2} \times B$$

$$\langle I_{PIIN}^2 \rangle = B\Re^2 \frac{P_{sr}^2}{N\Delta v} \sum_{i=1}^{N} \left\{ Y_{ij} \cdot \left[\sum_{K=1}^{K} d_K X_{ij} \right] \times \left[\sum_{m=1}^{K} d_m C_m(i) \right] \right\}$$

$$+B\Re^2 \frac{P_{sr}^2}{N\Delta v} \sum_{i=1}^{N} \left\{ \overline{X_{ij} \bullet Y_{ij}} \left[\sum_{K=1}^{K} d_K X_{ij} Y_{ij} \right] \times \left[\sum_{m=1}^{K} d_m C_m(i) \right] \right\}$$

By using Equation (22), Equation (24) and Equation (29) approximating the summation of $\sum_{m=1}^{K} d_m \; i)\, c_m \; i) \approx \frac{KW}{N}$ the variance of the receiver photocurrent can be expressed as;

$$\langle I_{PIIN}^2 \rangle \cong \frac{B\Re^2 P_{sr}^2}{N\Delta v} \cdot \left[\frac{KW}{N} \right] \times \sum_{j=1}^{j} \sum_{i=1}^{K} X_{ij} Y_{ij} + \frac{B\Re^2 P_{sr}^2}{N\Delta v} \cdot \left[\frac{KW}{N} \right] \sum_{K=1}^{K} \sum_{i=1}^{N} X_{ij} Y_{ij} (\overline{X_{ij} \bullet Y_{ij}})$$

$$\left\langle I^2{}_{PIIN} \right\rangle = \frac{B\Re^2 P_{sr}^2 KW}{N^2 \Delta v} [3W + 1] \quad (36)$$

Since, from Equation (11) until Equation (14), shown the properties of FCC code is unique and independent of each other, Equation (36) is also independent of the active users' data, consequently proposed coding systems does not depend on the timing of transitions in the user data and it applied to the asynchronous systems.

Thermal noise is given as [11];

$$I_{TN} = \frac{4K_b T_n B}{R_L} \quad (37)$$

From Equation (33), Equation (34), Equation (36) and Equation (37) the SNR for the proposed FCC spectral amplitude coding systems is defined by the mathematical expression as follows:

$$SNR = \frac{\left[\frac{\Re P_{sr} W}{N} \right]^2}{\left[\frac{2eB\Re P_{sr}}{N} \right][3W+1] + B\Re^2 \left[\frac{P_{sr}{}^2 KW}{N^2 \Delta V} \right][3W+1] + \frac{4K_b T_n B}{R_L}} \quad (38)$$

Since, there is no pulses are sent for the data bit '0'and assuming that the noise distribution is Gaussian, thus; the corresponding Bit Error Rate (BER) can be obtained as follows [10]:

$$P_e = \frac{1}{2} erfc\left(\sqrt{\frac{SNR}{8}} \right) \quad (39)$$

Finally, Equation (38) and Equation (39) will be used for the theoretical calculation for an evaluation of the proposed coding system using FCC code.

V. RESULT AND DISCUSSION

A. Various SAC-OCDMA Codes Comparison

In optical CDMA systems using *Spectral Amplitude Coding*, the length of the codes is an important parameter. Table 3 shows the weight *W*, the code length N and the cross-correlation λ_{max} for 30 users. It is clearly seen that the FCC code can be generated with lower code weights (W = 2) and shorter code length when compared to the other codes. It is also seen that the FCC code can have any desired cross-correlation values. It is desirable to have smaller code length as this will require smaller bandwidth and less number of filters at the encoder as well decoder, thus it will reduce the complexity and cost of the systems. From Table 3, it is proved that, there is no other code that can be generated with the code weight equal to two, except of the FCC code.

TABLE III
COMPARISON OF VARIOUS CODES USED FOR SAC-OCDMA

CODES	NO. OF USER (K)	WEIGHT (*W*)	CODE LENGTH (N)	CROSS-CORRELATION
MFH	30	7	42	1
MQC	30	8	56	1
MDW	30	4	90	1
KS	30	4	144	1
FCC	30	2	31	ξ{0,1}

B. Relationship between received power and PIIN noise.

In OCDMA systems, PIIN is strongly related to MUI due to the overlapping of spectra from different users. Figure 3 shows the relations between PIIN noise and received power (P*sr*). It is already shown previously that MUI can be almost reduced because of zero in phase cross-correlation which has been listed in the previously published papers at [13]. Thus, the effect of the MUI is not discussed further. The value of P*sr* is varied from -25dBm to 15dBm. When the received power increases the PIIN noise for MFH, MQC, MDW and FCC codes increases linearly. From figure shows, the PIIN noise in FCC code is not as much of others code, thus the PIIN noise can be effectively relegated using FCC code due to flexible cross-correlation as discussed in section three. Moreover, the weight is smaller than other OCDMA codes such as MFH, MQC and MDW.

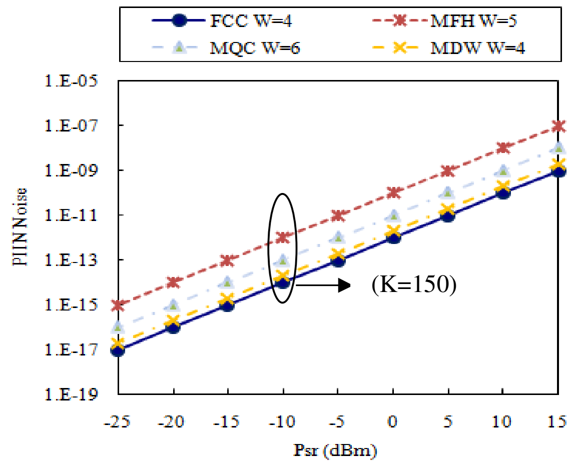

Figure 3: PIIN versus P_{sr} for various OCDMA codes with same number of user, K=150

C. Relationship between number of users and PIIN noise.

Figure 4 shows the relation between number of user and PIIN noise (where the effects of shot and thermal noise are neglected). The figure clearly shows that, the PIIN noise remains constant at 10^{-15} for K=150 even the number of users increasing simultaneously. In contrast, for MDW and MFH codes the PIIN noise increase when the number of simultaneous user increases. This is because of an algorithm property of the code design and construction (as mentioned is section three).

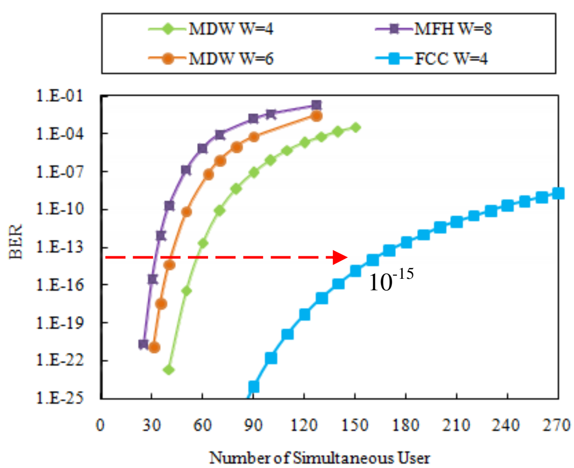

Figure 4: PIIN Noise versus number of user for P_{sr} = -10dBm

D. Effect of Number of Users on System Performance by Considering PIIN Only

Figure 5 shows the plot between number of simultaneous user and the system performance by considering only PIIN noise (where the effects of shot and thermal noise are neglected). It clearly shows that FCC code has better BER than MDW and MFH codes. It shows that the BER increases as the number of user increases. If PIIN noise been considered, then SNR is given as follows:-

$$SNR = \frac{W\Delta v}{K\left[3W+1\right]B} \tag{40}$$

In Equation (40), SNR depends on code weight *W*, number of user *K*, ΔV and *B.* However, the values of ***B***, and ΔV are fixed (ie. B = 311MHz and ΔV = 3.75THz) but *K* varied from 20 to 160 user. From figure 5 shows that, the system using FCC code can support much higher numbers of users than MDW (W= 4 and W=6) and MFH codes. This is truly proved with properties and arrangement of FCC code, thus PIIN noise can be suppressed.

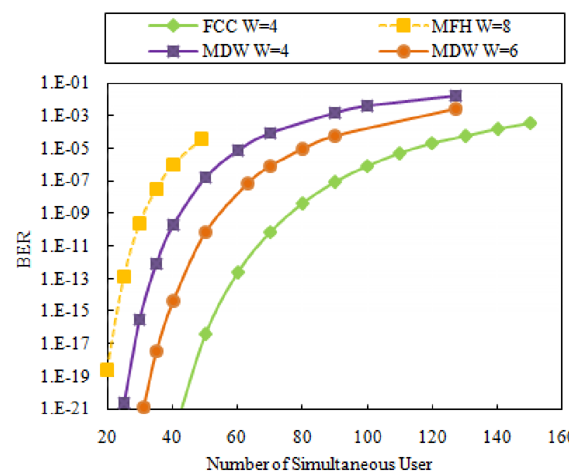

Figure 5: BER versus number of simultaneous user by considering PIIN noise only

VI. SYSTEM SIMULATION SETUP

The NAND subtraction technique [10] has been used as a detection method. The technique can be best described using Figure 6. This technique is fully capable of eliminating the PIIN, less complexity of encoder and decoder design thus improving performance of the system. From figure 6, a spectral amplitude signal at the receiver side is split into two parts. The first part is the signal for a user X related to cross-correlation between X and Y, and the second part should be a cross-correlation result from the NAND operation between X and Y, which have the same cross-correlation amplitude related to the signal in the first part.

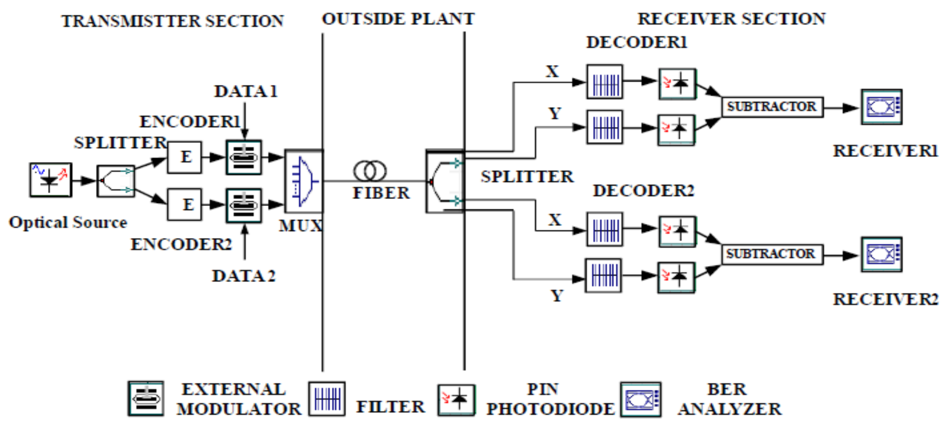

Figure 6: Block diagram of NAND detection scheme used for the FCC code [10].

E. Effect of Distance on System Performance

Figure 7 shows the variation of BER over the Distance for FCC code. The BER increased exponentially with distance. Means, for a long distance the higher BER will affect the signal. Various factors which can be responsible for this, for instance, longer fiber will provide a larger attenuation thus increasing the BER Attenuation is basically a transmission loss in optical fibers and it largely determines the maximum transmission distance prior to signal restoration. The test was used bit rate at 155Mbps, 622Mbps, 1Gbps and 2Gbps respectively for varies distance from 5 to 29km. At the BER threshold of 10^{-12}, the OCDMA system using FCC code could perform sufficiently well up to 17km and 30km for 622 Mbps and 155 Mbps respectively without any amplifier required, whereas the system using 1Gbps and 2Gbps could sufficiently perform only up to 10 km and 17km respectively. The results in figure 7 clearly show that OCDMA system using FCC code is suitable for the Fiber to The Home and LAN environment.

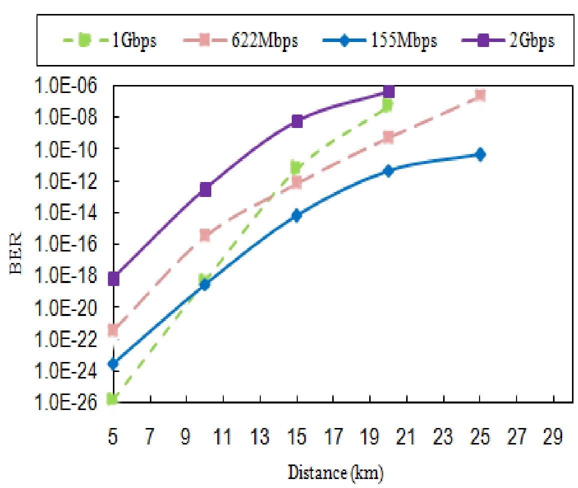

Figure 7: BER versus distance at different bit rate using FCC code

VII. CONCLUSION

We have proposed a new code algorithm and structure for SAC-OCDMA systems. The code properties, code construction and BER performance analysis of a spectral amplitude FCC OCDMA system has been derived by considering the effect of shot noise, intensity noise and thermal noise respectively. From the BER performance analysis we found that the proposed code structure can effectively alleviation the intensity noise and improve the BER performance as compared to other SAC-OCDMA codes such as MDW, MQC and MFH. This will give an offer in SAC-OCDMA system for better quality of service in optical access networks for future generation's usage.

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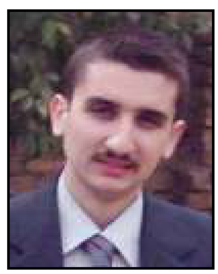

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