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New Design of Flexible Cross Correlation (FCC) Code for SAC-OCDMA System

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Abstract

In this paper, we present, several aspects of unipolar optical code-division multiple access (OCDMA) codes, focusing on the flexible in-phase cross-correlation code algorithm and its potential for future optical networks. We briefly present a new class of code namely Flexible Cross Correlation (FCC) code for Spectral-Amplitude Coding (SAC) OCDMA approaches. The main coding properties are reviewed. The FCC code provides simple tridiagonal matrix constructions compared to the other SAC-OCDMA codes such as MDW, MQC and MFH codes. This code possesses such a various advantages, including the easier code construction, less complexity of encoder/decoder design and flexible in-phase cross-correlation for uncomplicated to implement using Fiber Bragg Gratings (FBGs) for the OCDMA systems.

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Keywords: Flexible Cross Correlation Code; Multiple Access Interference; Code Length; Fiber Bragg Gratings; SAC-OCDMA.

1. Introduction

Optical Code Division Multiple Access (OCDMA) is one of the technologies that promising the implementation of all optical networks, which has potential to exploit the previously unmanned bandwidth instead of TDMA and WDMA. TDMA and WDMA are used in the fiber optic communication by dividing a bandwidth among multiple users. TDMA is a technology that allows multiple users to access a channel by allocating time slots to each user within each channel .WDMA is a technology allowing multiple users to access a channel by allocating wavelength or frequency to each user within each channel. TDMA and WDMA have a limited bandwidth for every user [1]. Interests in OCDMA always have enormous demand for bandwidth due to internet access, including electronic commerce and tele-networking. Due to that, it is important to note that an OCDMA system is to design code sequence with flexible cross correlation to easily distinguish the intended signal from the interfering signal. Therefore, the selection of the optical code and coding architecture used in the system must be considered together to attain best quality services from the network [2]. In OCDMA systems, Multiple Access Interference (MAI) is the main reason for performance degradation especially when a large number of users is involved [3]. The primary objective of OCDMA system is to design a code sequence; with low cross correlation to eliminating the effects of MAI to the total receives power [4]. Several optical codes have been proposed for OCDMA systems such as Modified Frequency Hopping (MFH) code [5], Optical Orthogonal Code [6], and Modified Double Weight (MDW) code [7]. However, these codes suffer from certain limitations such as the code length either too long (e.g. Optical

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Orthogonal Codes), construction are complicated or cross correlation are not ideal. In this paper, proposed code called Flexible Cross Correlation (FCC) code has been proposed with flexible in-phase cross correlation to ensure that each codeword can be easily distinguished from every other address sequence. The FCC codes are easier to generate and it is optimum in the sense that, the code length is shorter for a given large cardinality (number of users), weights and flexible cross correlation to eliminate the effects of MAI.

2. Essential of OCDMA Codes.

Optical codes are family of K (for K users) binary [0, 1] sequences of length, N, maximum cross correlation, λ_{max} and weight *w* (the number of "1" in each codeword). The optimum code set is one having minimum cross- correlation properties to support the maximum number of users with minimum code length [8]. 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 [9].

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

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

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 $\lambda_a(\tau)$ in Equation (3) is for τ=0 and is equal to *w*, the weight of the sequence. Thus,

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

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 weight *w* can be written as (N,*w*, $\lambda_{xm,}$ λ_{xym}) or (N, *w*, λ_{max}), where λ_{max} = max {$\lambda_{xm,}$ λ_{xym}}. It may also be noted that for an optical code a_n with weight '*w*'

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

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 $\lambda_{abm.}$ The codes described by Equation (1) can also be represented in vector form as:

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

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,

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

$$\lambda_{AB(0)} = AB^T \tag{8}$$

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

3. Design of Flexible Cross Correlation Code.

Step 1: Consider a set of K, flexible in-phase cross correlation codes of length N and weight w for K users. The set of codes can be represented by the K rows of the KxN matrix. A_K^w whose elements a_{ij} are given by:

$$A_K^w = \left\{ a_{ij} = '0' \; or \; '1', i = 1,2,..K, j = 1,2,..N \right\} \tag{9}$$

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

$$N \geq K \tag{10}$$

The set of code matrix can be represented by the K rows of the KxN matrix A_K^w whose elements a_{ij} are given by Equation (9) where, A_K^w is a KxN Matrix whose each row of the matrix A_K^w representing an optical code. The weight of each of the K codes is assumed to be w. The matrix A_K^w is given by Equation (11) and the rows A_1, A_2, A_K represent the K code words.

$$A_K^w = \begin{bmatrix} a_{11} & a_{12} & a_{13} & \cdots & a_{1N} \\ a_{21} & a_{22} & a_{23} & \cdots & a_{2N} \\ \vdots & \vdots & \vdots & & \vdots \\ a_{K1} & a_{K2} & a_{K3} & \cdots & a_{KN} \end{bmatrix} = \begin{bmatrix} A_1 \\ A_2 \\ \vdots \\ A_K \end{bmatrix} \tag{11}$$

Where,

$$A_1 = a_{11}, a_{12}, ...a_{1N}$$
$$A_2 = a_{21}, a_{22}, ...a_{2N}$$
$$A_K = a_{K1}, a_{K2}, ...a_{KN}$$

Step 2: The K codes represented by the K rows of the code matrix A_K^w in Equation (11) are to represent a valid set of K codeword with Flexible in Phase Cross Correlations λ_{max} and weight w it must satisfy the following conditions:

1.For the code to have weight w,

$$\sum_{j=1}^{N} a_{ij} = w, \; i = 1,2...K \tag{12}$$

2. The Flexible In Phase Cross Correlation, λ_{max} between any of the K code words (K rows of the matrix A_K^w) should not exceed λ_{max}.

$$A_i A_j^T = \begin{cases} \leq \lambda_{\max} & for \; i \neq j \\ = w & for \; i = j \end{cases} \tag{13}$$

3. 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,

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

4. All K rows of 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 above four conditions is the KxN Matrix A_K^w whose i[th] row is given by,

$$A_i = \overset{r(i-1)}{0...0} \quad \overset{w}{11..1} \quad \overset{r(K-i)}{0...0} = N \tag{15}$$

The length N of the code 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

Step 3: On the basis of the above discussions, the construction of an optical code having a value of K, *w,* λ_{max} consists of the following steps:

1).For a given number of users K, and weight *w*, form a set of flexible in-phase cross correlation code with a 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, weight *w* and minimum code length.

Step 4: Assume that, it is desired to generate a set of minimum length flexible in-phase cross correlation optical codes for eight users, weight is equal to three and λ_{max} equal to two. Here K=8, *w*=3 and λmax=2, the Code Matrix, A_K^w for this code is,

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

Hence, Table 1 shows the required flexible in- phase cross correlation for the codeword for K=8, *w*=3 and λ_{max}=2 are,

Table 1. FCC codeword K=8, *w*=3, 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	$= \{0\ 0\ 0\ 0\ 0\ 0\ 0\ 1\ 1\ 1\}$

The FCC code shown superior code design with (N, *w*, λ_{max}) parameters to obtain large number of active users compared with existing OCDMA codes. Finally, with the properties of FCC code, the SNR for FCC code is defined with mathematical expression as follows;-

$$SNR = \frac{\left(\frac{\Re P_{sr} W}{N}\right)^2}{\frac{2eB\Re P_{sr}\left(W+3\right)}{N} + \frac{B\Re^2 P_{sr}^2 KW(W+3)}{N^2 \Delta v} + \frac{4K_b T_n B}{R_L}} \tag{17}$$

While the Bit Error Rate (BER) can be calculated using Gaussian approximation as follows [6]:-

$$BER = \frac{1}{2} erfc\left(\sqrt{\frac{SNR}{8}}\right) \tag{18}$$

4. Results and Discussion

In optical CDMA systems using *Spectral Amplitude Coding*, the code length is another factor to be considered. Table 2 shows it is desirable to have shorter codes length as this will required smaller bandwidth. Moreover, codes with smaller length will require less number of filters at the encoder as well decoder [8]. This will reduce the complexity and cost of the systems.

Table 2. Various SAC-OCDMA Codes for Code Length Comparison

CODES	NO. OF USER (K)	WEIGHT (*W*)	CODE LENGTH (N)	CROSS CORRELATION λ_{max}
MFH	30	7	42	1
MDW	30	4	90	1
FCC	30	2	31	($\lambda_{max} \leq 1$).

Figure 1 shows the encoder and decoder design for the proposed code. It is a simple technique in comparison with other existing detection techniques. It consists of three parts. At Transmitter part, the source should be a broadband light source with high spectral power density, which makes LED as a good candidate to be used. The code will be encoded using an external modulator and ready to transmit through the fiber. Single mode fiber (SMF) is being used for the system performance comparison and the length of the fiber depending on the parameter design to observe the performance. At the receiver part, the noise generated at the receivers was set to be random and totally uncorrelated. We used Fiber Bragg Grating (FBG spectral phase decoder operates to decode the code. The decoded signal was decoded by a photo-detector (PD) followed by the low pass filter (LPF) and error detector respectively. The performance of the system was characterized by referring to the bit error rate (BER).

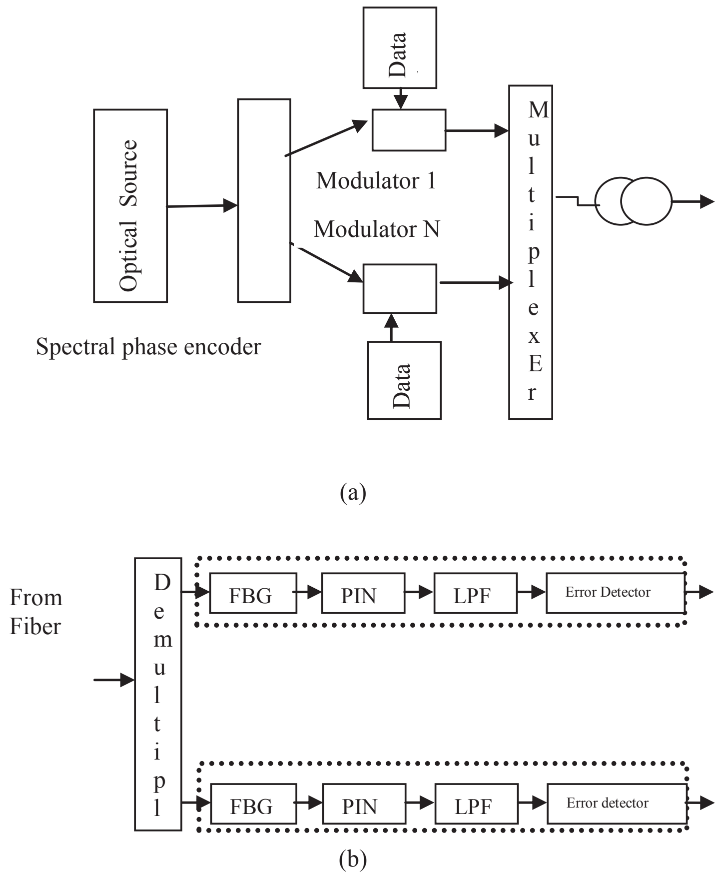

Fig. 1. Encoder and Decoder Design for the FCC Code a) Transmitter Plant b) Receiver Plant

Figure 2 shows the plots between the number of active users and BER It clearly depicts that FCC code had shown superior performance BER as compared to MFH and MDW codes. It shows that the Bit Error Rate (BER) increases as the number of active users increases. SNR depends on code weight *w*, the number of users K, ΔV, B and K_B (Boltzman Constant). However, the values of B and ΔV are fixed. (i.e B=311MHz and ΔV=3.75THz). The values of K vary from 10 to 150 users. At BER = 10^{-09} the cardinality (the number of active users) of FCC code improves 60%, 128% and 175% in comparison to, Frequency Hoping (MFH) code, Modified Double Weight (MDW *w*=4) code and Modified Double Weight (*w*=6) respectively.

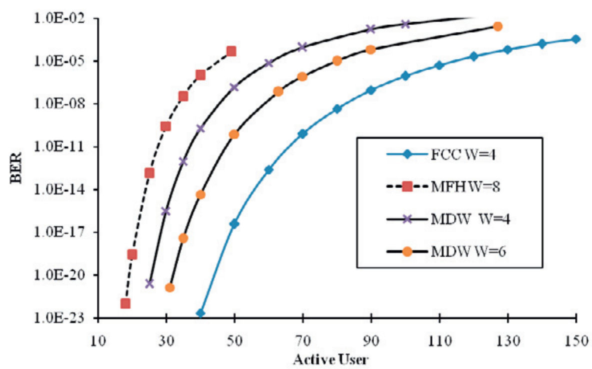

Fig. 2. BER versus Number of Active Users for Various OCDMA Codes

Figure 3 shows the P_{sr} and system performance (BER) when the number of simultaneous users is 80. The values of P_{sr} are varied from -25dBm to -15dBm. Here, we have considered the effects of the shot, intensity and thermal noises respectively. It had shown that FCC code gives much better performance contrast with MFH, MQC and MDW codes when the effective receive power P_{sr} is large (when P_{sr}>-22dbm). When the P_{sr} for all OCDMA codes at the lower values (when P_{sr}<-22dbm), the performance of all OCDMA codes shown nearly the same. Systems with proposed codes can have better receive power without any amplifier required.

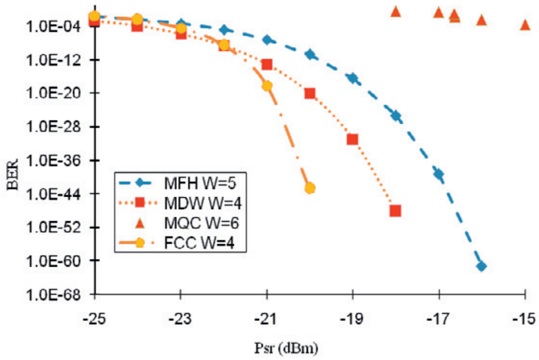

Fig 3: BER versus Power receive, P*sr* for Various OCDMA Codes.

Figure 4 shows the variation curves of the BER versus distance for FCC and MDW codes at *w*=4. The various factors which can be responsible for this, for instance, longer fiber will provide a larger, thus increasing the Bit Error Rate. Attenuation is basically a transmission loss in optical fibers and it largely determines by maximum transmission distance. From figure shows, the system performs sufficiently well up to 15km for 155Mbps, 622Mbps and 1Gbps. Overall the performance of 155Mbps is better than 622Mbps and 1Gbps because it is increasing very smoothly and well up to 30km with better BER. The result above clearly shows that system with FCC at 155Mbps is suitable for FTTH and LAN network.

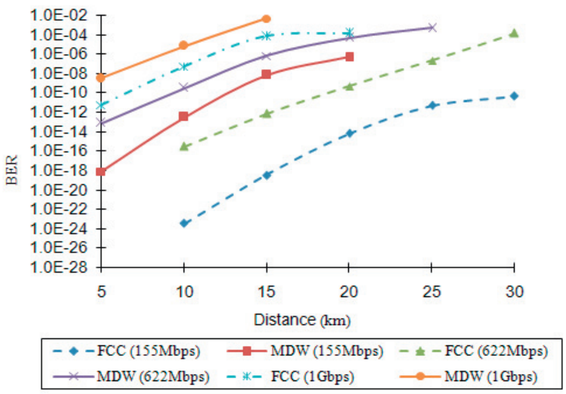

Fig. 4. BER versus Distance at Different Bit Rate for FCC and MDW codes with *w*=4.

5. Conclusion

A new class of flexible cross- correlation code for OCDMA system was proposed. We have shown that, the proposed code has superior performance in term of 1) easier code construction 2) shorter code length given any number of users and weights. It is desirable to have code with flexible cross- correlation to overwhelm the Multiple Access Interference (MAI) been affecting performance of OCDMA systems even large number of users are involved. Systems with FCC code will, therefore, the efficiency of transmission will increase and produce better performance in the presence of noise. Finally, the proposed FCC code is suitable for future optical access network technologies.

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