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PERFORMANCE ANALYSIS OF A NEW CLASS OF CODES WITH FLEXIBLE CROSS CORRELATION FOR SAC-OCDMA SYSTEM

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ABSTRACT

Design and analysis of a new class of code for the Spectral Amplitude Coding-Optical Code Division Multiple Access (SAC-OCDMA) system is presented. The proposed code is called the Flexible Cross Correlation (FCC) code. The FCC code has advantages such as the flexibility in-phase cross-correlation given any number of users and weights. These proposed codes can effectively suppress Phase Induced Intensity Noise (*PIIN*), has the Multiple Access Interference (MAI) cancellation property and easy in the code construction. We found that, from the theoretical analysis, FCC code had better achievement indicated that, the FCC code can accommodate 240 simultaneous users as compared to former SAC-OCDMA codes. FCC code also has low effective receive power (Psr) equal to -21 dBm at error floor 10^{-9}. The extensively simulation results, FCC code are well up to 45 km at system performance BER 10^{-9} for bit rate 155 Mbps as compared to 622 Mbps only perform 10 km with exponentially increases to BER 10^{-2} error floor.

Keywords: *FCC Code, MAI, SAC-OCDMA, PIIN, Optical Transmission*

1. INTRODUCTION

Code Division Multiple Access (CDMA) has been well studied in the wireless communication systems. Recently, the spread spectrum technique has gotten a lot of attention in the optical fiber transmission due to the inherent large bandwidth of fibers. OCDMA has several benefits such as asynchronous transmission, flexibility in network design, accommodation of burst traffic and variable bit rate traffic [1]. Nevertheless, the OCDMA systems suffer from certain noises such as *PIIN*, *Shot* noise and *Thermal*, respectively [2]. In addition, MAI is the main performance degradation especially when a large number of users are involved in the OCDMA systems [3]. Therefore, the most important consideration is the code designs for reducing contribution at the MAI to the optical power receive. Among all OCDMA techniques, SAC has the advantages of suppressing the effect of MAI when codes with flexible in phase cross-correlation is utilized as address sequence and balance detection at the receiver side [4]. Most codes have been proposed for the SAC-OCDMA systems such Modified Frequency Hopping (MFH), Modified Double Weight (MDW) [5-6] codes. However, these codes have several limitations such as the code is either too long (e.g. MFH code) and construction is complicated and fixed an even natural number for MDW code. Thus, we have proposed a new algorithm of Flexible Cross Correlation (FCC) code which is designed with a simple tridiagonal code matrix whereas the main elements are diagonal and the i^{th} row is shifting method. The FCC code has several advantages such as 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 and easy code construction. Finally, we analyzed the FCC code with the mathematical numerical and exhaustive optical simulator called *Optisystem* software from *Optiwave*, which we consider the effects such as four wave mixing and self phase modulation were activated with specification to simulate as close as the industrial real environment

2. FCC CODE DEVELOPMENT

Optical codes are family of K (for K users) binary [0, 1] sequences of length N, code weight W (the number of “1” in each codeword) and the maximum cross-correlation, λ_{max}. In OCDMA system, 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.

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Step 1;

The set optical code consists of (N, W, λ_{max}) FCC code for K users. The KxN code matrix A_K^W is here called the **Tridiagonal Code Matrix.** These sets of codes are then represented by;

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

where,

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

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;

After the K codes represented by the K rows of the KxN code matrix A_K^W in equation (1), are to represent a valid set of K codeword with in phase cross-correlations λmax and code weight W; it must satisfy the following conditions:

1. The elements {aij} of A_K^W must have values "0" or "1"

aij = "0" or "1" for i=1,2,..K, j=1 2,..N (2)

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,

$$X_i X_j^T = \begin{cases} \le \lambda_{max} & for\ i \ne j \\ = W & for\ i = j \end{cases} \quad (3)$$

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

$$\sum_{j=1}^{N} a_{ij} = W, \ i = 1, 2 \dots K \quad (4)$$

4. From equation (3), 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, $W > \lambda_{max.}$

5. All K rows of A_K^W should be linearly independent because each codeword must be uniquely different from other codewords. That is to say the rank of the KxN matrix, A_K^W should be K. Moreover, for A_K^W to have rank K, thus codes $N \ge K$.

Step 3;

From the five 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;

$$A_i = \overbrace{0\dots0}^{r(i-1)} \ \overbrace{11..1}^{W} \ \overbrace{0\dots0}^{r(K-i)} \quad (5)$$

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

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

It can be seen that the length N is minimum under the assumed conditions. Table 1 shows the FCC code for a given number of users K=5, weight W=4 and flexible cross-correlation $\lambda_{max} \le 1$

Table 1: Example of FCC code

$A_i = r(i-1)$, W, $r(K-i)$

K_1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
K_2	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0
K_3	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0
K_4	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0
K_5	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1

3. PERFORMANCE ANALYSIS

In our analyses, we only considered 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 SNR is defined as the average of the signal-to-noise ratio, SNR= $[I^2/\sigma^2]$ where σ^2 is the mean power of noise which is given by [2];

$$\sigma^2 = 2eBI + I^2 B\tau_C + \frac{4K_b T_n B}{R_L} \quad (7)$$

where, e is the electron's 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 absolute receiver noise temperature, R_L is the receiver load resistor and τ_c is the coherence source time. Only one PSD spectrum will be calculated and the photodiode current I can be written as follows;

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$$I = \Re \int_0^{\infty} G(v)\, dv \tag{8}$$

$\Re$ represents as the responsivity of the photo-detectors. Consequently, the photo current I can be expressed as;

$$I = \Re \left[\frac{P_{sr} W}{N} \right] \tag{9}$$

The mean power of shot noise can be written as;

$$I_{shot} = 2eB\Re \left[\frac{P_{sr}}{N} \right] [W+3] \tag{10}$$

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 and 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;

$$I^2{}_{PIIN} = \frac{B\Re^2 P_{sr}^2 KW}{N^2 \Delta v} [W+3] \tag{11}$$

Thermal noise is given as [1];

$$I_{TN} = \frac{4K_b T_n B}{R_L} \tag{12}$$

From equations (9), (10), (11) and (12) the SNR for the proposed FCC code SAC-OCDMA coding systems is defined by the mathematical expression as follows;

$$SNR = \frac{\left[\frac{\Re P_{sr} W}{N} \right]^2}{\left[\frac{2eB\Re P_{sr}}{N} \right][W+3] + B\Re^2 \left[\frac{P_{sr}{}^2 KW}{N^2 \Delta V} \right][W+3] + \frac{4K_b T_n B}{R_L}} \tag{13}$$

Since, there is no pulses are sent for the data spacing assuming that the noise distribution is Gaussian thus, the corresponding bit-error rate (BER) can be obtained as follows [1];

$$P_e = \frac{1}{2} erfc \left(\sqrt{\frac{SNR}{8}} \right) \tag{14}$$

Finally, the equations (13) and (14) will be used for the numerical calculation for an evaluation of the proposed coding system using FCC code.

4. RESULTS AND DISCUSSIONS

Figure 1 shows the variation plots of the system BER versus the number of simultaneous users for FCC code (W=4) with various SAC-OCDMA codes such as MDW (W=4) and MFH (W=8) codes for the effective receive power Psr = -10 dBm. It had shown that, system BER degrade as the number of simultaneous users increased. At performance analysis BER = 10^{-9} the system with FCC code (W=4) can accommodate 240 numbers of simultaneous users, which is the highest cardinality as compared to the former SAC-OCDMA codes. We can ascertain that, the FCC code had indicated good performance due to arrangement of code algorithm and flexibility in phase cross-correlation.

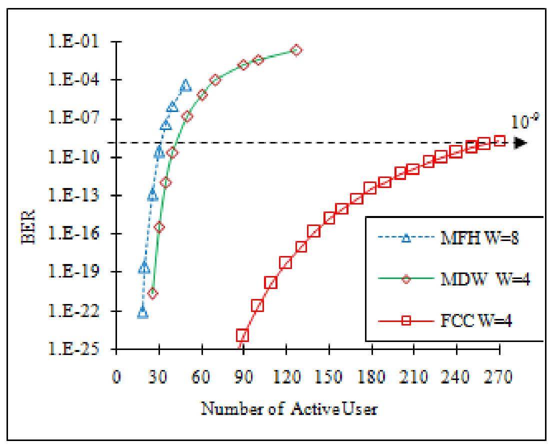

Figure 1: BER versus Number of Active Users for Various SAC-OCDMA Codes.

Figure 2 shows BER versus Psr for number of users is equal to 240. Here, we consider *Shot*, *PIIN* and *Thermal* noises, respectively. The values of effective receive power, P_{sr} are varies from -50 dBm to 20 dBm. It had shown that, FCC code has better performance contrast with MDW and MFH codes when the effective receives power P_{sr} is large (when P_{sr} >-20 dBm). When the P_{sr} for SAC-OCDMA codes at the lower values (when P_{sr} <-20 dBm), the performance of all SAC-OCDMA codes had shown same values of BER 10^{-3}. SAC-OCDMA coding system with FCC code can have better power receives P_{sr} = -21 dBm with BER is equal to 10^{-9} without requiring any amplifier.

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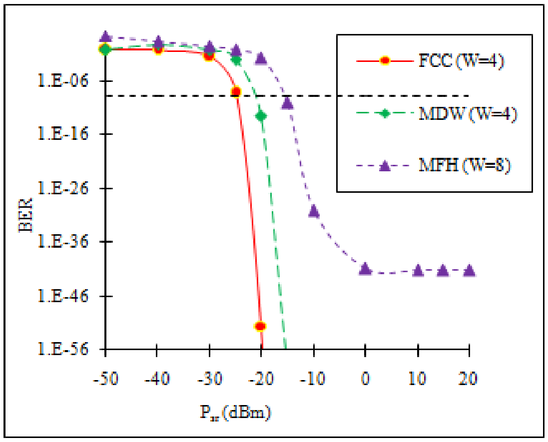

Figure 2: Effective Receive Power, P_{sr} versus BER for Various SAC-OCDMA code.

We observe from Figure 3 the plots between fiber length and system performance BER for FCC (*W*=4) code for different 155 Mbps and 622 Mbps bit rates. It can be seen that, at system performance BER 10^{-9} FCC (*W*=4) 155 Mbps significantly have better system performance BER where it is capable of achieving an acceptable system performance BER up to a fiber length 45 km. It is different when the FCC (*W*=4) 622 Mbps, only can perform up to 10 km with the same threshold system performance BER. From this observation, FCC (*W*=4) at 155 Mbps can successfully eliminate and suppressed the effects of *PIIN* and MAI for the SAC-OCDMA coding system.

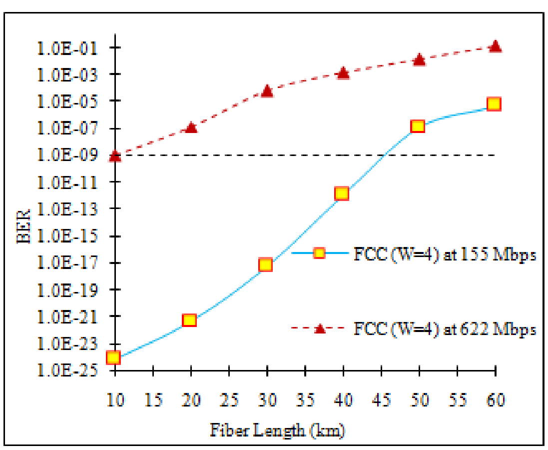

Figure 3: Fiber Length versus BER for FCC Code at Different Bit Rates

Furthermore, the BER performance is investigated by simulating three users of FCC code using *OptiSystem* software from *Optiwave*^{TM}. Figure 4 shows the variation traces back-to-back system BER versus various effective receive power P_{sr} for FCC code taking into account the *PIIN*, *Shot* and *Thermal* noises, respectively. It can be seen that, the theoretical results on BER with effective receive power P_{sr} = -10 dBm are close to the simulation results. The margin between the numerical and simulation results is about -6 dBm and it is equivalent to marginal -36 dB at effective receive power P_{sr} from -22 dBm to -16 dBm points.This is because it is quite difficult to achieve fix effective receive power in simulation rather than that of theoretical results. Furthermore, there are insertion losses in the components used in simulation which are not included in the theoretical formula as mentioned in equations (13) and (14).

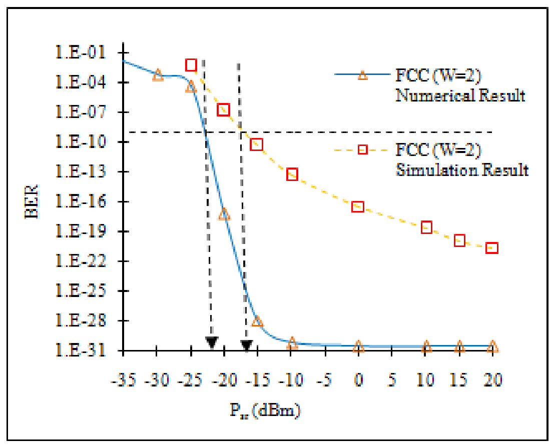

Figure 4: Validation between Numerical and Simulation Results of FCC Code When P_{sr}= -10 dBm

5. CONCLUSIONS

The system degradation due to *PIIN* can be suppressed using flexible cross-correlation property offered by FCC code, results in enhancing BER performance. The proposed FCC code is robust in term of received power, P_{sr} as well as a reliable number of simultaneous users. The performance of the proposed FCC code achieves high cardinality (number of simultaneous users) and low received power in comparison to MDW and MFH codes.

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