Design of a New Class of Codes with Zero in Phase Cross Correlation for Spectral Amplitude Coding

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Summary

This paper presented the design of a new class of zero cross correlation optical code for Optical Code Division Multiple Access (OCDMA) system using Spectral Amplitude Coding. The proposed code namely Modified Zero Cross Correlation Code (MZCC). The proposed code has minimum length and can be constructed easily for a given number of users and weights. The proposed code has shown superior performance compared with existing optical codes such as ZCC code. The proposed code was demonstrated in simulation using OptiSys. 6.0 to observe the system performance with the presence of noise.

Key words:

Spectral Amplitude Coding,Phase Induce Intensity Noise, Modified Zero Cross Correlation, Optisys 6.0, Multi Access Interference.

1. Introduction

In OCDMA systems Multi Access Interference (MAI) is the main reason for performance degradation especially when large numbers of users are involved [1, 2]. In Spectral Amplitude Coding OCDMA systems, given a user number and a code length, MAI is only determined by the values of zero in-phase cross correlation between the address sequences because frequency components are inherently in order [3]. One major advantage of such systems is that eliminating MAI with fixed cross correlation is used as address sequences. This elimination is realized by balanced detection of signals from a normal decoder and a reference decoder [3]. Nevertheless, in Spectral Amplitude Coding systems, the inherent Phase Induced Intensity Noise (PIIN) also severely affects the overall system

performance [4]. This noise is due to spontaneous emission of the broadband source. To suppress it, the value of cross correlation between the codes should be kept as small as possible preferably less than or equal to 1 [5]. Optical CDMA system should have an efficient address code sequences with good auto and cross correlation properties. It is important to note that an optical CDMA system must be evaluated with considering the performance (i.e. correlation properties) of the selected optical codes. The coding architecture (i.e. the structure of the optical encoders and decoders) is another important factor to consider, since it affects the power budget, size, cost, and eventually the feasibility of the whole system. 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 [1, 2, 7]. Several optical codes have been proposed for OCDMA systems such as Hadamard code, Prime Code, Modified Frequency Hopping (MFH) code, Optical Orthogonal Codes, and Modified Double Weight (MDW) code. However, these codes suffer from certain limitations such as the code either too long (e.g. Optical Orthogonal Codes and Prime Code), construction are complicated or cross correlation are not ideal.

Recently, an interesting method for the design of Zero Cross Correlation Code called “Zero Cross Correlation Code (ZCC)” is presented [14]. The code structure does not have overlapping of bits ‘1’ and does not cause ZCC code to interfere between users, thus suppressing PIIN. However, the code length is not minimum for a given number of users and weights. Moreover, it can only be designed for specified number of user and weight.

In this paper, code called Modified Zero Cross Correlation (MZCC) has been developed with in-phase cross correlation equal to zero which ensures that each codeword can be easily distinguished from every other address sequence. The code is optimum in the sense that the length of the code is minimum for a given auto- and cross- correlation function and can be constructed for any number of users. In other words, the MAI is made insignificant compared to the energy contained in the received information bit [6]. The MZCC code is easier to generate for any number of users and for any given weight. Furthermore, the code has better performance with the presence of noise.

2. Development of The Proposed Code

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2.1 Essential Zero Cross Correlation Code

Zero Cross Correlation optical codes are family of [0, 1] sequences of length, N and weight w (the number of “1” in each codeword). The autocorrelation of each codeword $X = (x_1, x_2, \ldots x_N)$ and the cross correlation between any two distinct codeword $X = (x_1, x_2, \ldots x_N)$ and $Y = (y_1, y_2, \ldots\ldots. y_N)$ satisfy the following [13]:

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

$$\lambda_{xy}(\tau) = \sum_{i=1}^{N} x_i y_{i+\tau} = 0 \quad \text{for } \tau=0 \tag{2}$$

The optimum code set is one having good auto and cross correlation properties to support maximum number of users with minimum code length. 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.

2.2 Mathematical Preliminaries

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

$$a_i, = \text{‘0’ or ‘1’}, \quad i= 0,\ldots N\text{-}1 \tag{3}$$

$$b_i, = \text{‘0’ or ‘1’}, \quad i=0,\ldots N\text{-}1$$

The auto and cross correlation functions of thesequences are defined, respectively, by

$$\lambda_x(\tau) = \sum_{n=0}^{N-1} x_i x_{i+\tau} \tag{4}$$

$$\lambda_{x,y}(\tau) = \sum_{n=0}^{N-1} x_i y_{i+\tau} \tag{5}$$

Since an is a {0, 1} binary sequence, the maximum value of $\lambda_x(\tau)$ in Equation (4) is for $\tau = 0$ and is equal to w, the weight of the sequence. Thus,

$$\lambda_x(0) = w \tag{6}$$

If λxm & λxym 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, λxm, λxym) or (N, w, λmax), where λmax = max {λxm, λxym}. It may also be noted that for an optical code an with weight ‘w’

$$\lambda_{x\max} = \lambda_x(0) = \sum_{n=0}^{N-1} x_i x_i = w \tag{7}$$

In practice for K users, it is required to have K number of codes in a set for given values of N, w, λxm and λxym. The codes described by Equation (3) can be also represented in vector form as:

$$A=a_i \text{ for } i=0,1,..N\text{-}1 \tag{8}$$

$$B=b_i \text{ for } i=0,1,..N\text{-}1$$

Where A and B are vectors of length N with elements as defined by Equation (8). In term of the vectors A and B, Equation (4) and Equation (5) are written as,

$$\lambda_{A(0)} = AA^T = w \tag{9}$$

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

Where AT and BT denote the transpose of vectors A and B respectively.

2.3 Code Development

Optical zero cross- correlation codes are sets of optical sequences that require,

$$\lambda_{AB}(\tau) = 0 \ for \ \tau = 0 \tag{10}$$

That is,

$$ABT = 0$$

In fiber optic CDMA system to allow receivers to distinguish each of the possible users, to reduce channel interference and to accommodate large number of users, optical zero cross correlation codes should have large values of *w* and the size K. However, it is difficult to design such an optical orthogonal code which satisfied all the requirements, for example the condition expressed in Equation (10) is only achieved at the expanse of the smaller values of '*w*' or larger values of code length N or smaller values of code size K. Consider a set of K, Zero 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

$$A_K^w = \left\{ a_{ij} = '0' \ or \ '1' \quad \begin{matrix} i = 1,2,\ldots K \\ j = 1,2,\ldots N \end{matrix} \right. \tag{11}$$

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 each other. A_K^w should have rank K. More over for A_K^w to have rank K,

$$N \geq K \tag{12}$$

Thus, for A_K^w to represent a valid set of K, Zero Cross Correlation codes of weight w, it must satisfy the following conditions:-

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

$$aij = \text{"0" or "1" for } i=1,2..K, \quad j=1,2,..N \tag{13}$$

2. The weight of each code should be equal to w where, (14)

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

3. The in- phase auto- correlation of each code for $\tau = 0$ in Equation (10) must be equal to w. That is,

$$\sum_{j=1}^{N} a_{ij}^{\ 2} = AA^T = w \tag{15}$$

Note that Equation (14) and Equation (15) are same since aij = "0" or "1".

4. The set of K code words represented by the K rows of the code matrix $(A_K^w)(A_K^w)^T$ must form an orthogonal set (Zero Cross Correlation) that is must be a KxK diagonal matrix with w as diagonal elements. This is given by,

$$(A_K^w)(A_K^w)^T = D_K^w \tag{16}$$

Where, D_K^w is a KxK diagonal matrix with w as it diagonal elements as shown below,

$$D_K^w = \begin{bmatrix} w & 0 & \cdots 0 \\ 0 & w & \ldots 0 \\ \vdots & \vdots & \ddots \vdots \\ 0 & 0 & \ldots w \end{bmatrix} \tag{17}$$

For w=1 and for K users, one of the code matrices that satisfies the conditions as represented by Equations (13-16) and has the minimum possible length N is the KxK identity matrix P_k whose elements P_{ij} are given by,

$$\begin{aligned} P_{ij} &= 1 \, for \ i = j \\ &= 0 \, for \ i \neq j \end{aligned} \tag{18}$$

The KxK matrix Pk is called the Unit Code Matrix.

$$P_K = \begin{bmatrix} 1 & 0 & \cdots 0 \\ 0 & 1 & \ldots 0 \\ \vdots & \vdots & \ddots \vdots \\ 0 & 0 & \ldots 1 \end{bmatrix}_{KxK} \tag{19}$$

Notice that, the minimum length, N of the code is given by,

$$N = wK \tag{20}$$

The length N of each code in N = wK and is minimum under the assumed conditions.
Thus, the required Modified Zero Cross Correlation Codes are

$$\begin{aligned} A_1 &= 1 \quad 0 \quad 0 \\ A_2 &= 0 \quad 1 \quad 0 \\ A_3 &= 0 \quad 0 \quad 1 \end{aligned}$$

3. Performance Evaluation and Comparison

3.1 Code Length

In optical CDMA systems using *Spectral Amplitude Coding*, the length of the code is an important parameter. It is desirable to have smaller code length as this will required smaller bandwidth. Moreover, code with smaller length will require less number of filters at the encoder as well decoder [19]. This will reduce the complexity and cost of the system.

Given a number of users and weights, Table 1 shows the comparison of code length for the MZCC, ZCC and OOC codes. It can be seen from the table that for any given number of users K and code weight w the MZCC code has the minimum length. Thus, systems using MZCC code will be better in term of power received at the receiver, complexity and bandwidth requirement. For the same, transmitted power, systems with MZCC code will, therefore, have better performance in the presence of noise.

3.2 Code Weight

As has been discussed details above, the MZCC code proposed in this paper can be designed for any given number of users K and code weight w. However, this is not true with the ZCC code. In the case of ZCC code, the number of user K is related to the weight w of the code by the following relation,

$$K = w + 1 \qquad (21)$$

From Equation (21), it is seen that the variable w and K are not independent. Thus, it is not possible to obtain the ZCC code for any given number of users and code weight. For example for w=3, the code does not exist for two or three users.

Table 1: Code length (N) comparison between MZCC, ZCC and OOC codes

Users, (K)	**Weight, (*w*)**	**MZCC**	**ZCC**	**OOC**
		N	**N**	**N**
2	3	6	12	13
3	4	12	20	40
4	5	20	30	85
5	6	30	42	156
6	7	42	56	253
7	8	56	72	393
8	9	72	90	577
9	10	90	110	811
10	11	110	156	1101

4. Simulation Results

The performance of codes was simulated using OptiSys version 6.0. A simulation schematic was illustrated in Figure 2, and the simulation parameters are shown in Table 2.

Table 2: MZCC and ZCC codes Simulation Parameters

Parameters	**Values**
Data Rate (bps)	155, 622, 1G
Electron Charge	1.602e-19
Operating Wavelength	1550nm
Attenuation	0.2 db/km
Thermal Noise Coefficient	1.0 x 10-22 W/Hz
Dispersion	16.75 ps/nm-km
Fiber Length (KM)	5 - 30

Figure 3 gives the variation curves of the BER versus Distance for MZCC and ZCC codes. Various factors which can be responsible for this, for instance, longer fiber will provide a larger, thus increasing the Bit Error Rate (BER). Attenuation is basically a transmission loss in optical fibers and it largely determines by maximum transmission distance. The system performs with MZCC code sufficiently well up to 15km for 155Mbps, 622 Mbps and 1Gbps. Over all the performance for 155 Mbps is better than 622 Mbps and 1Gbps because it is increasing very smoothly and well up to 30km within typical range of BER 10-9 to 10-12. Figure 4 shows the BER against power receive at the receiver section. It is clearly shown that BER will decrease as the increasing of the receive power. This is due to attenuation effect while travelling in the fiber. This is superior performance for the system with MZCC code that only required small receive power at the receiver without adding any pre-Amplifier at distance varies from 5 to 30km with Input power is 10dbm.

CONCLUSIONS

In this paper, a new class of zero cross correlation code for OCDMA system was proposed. The code can be constructed simply and easily for any number of users and for any given weight to have the minimum code length. The MZCC presented in this paper has a better performance with the presence of noise as compared to the existing optical codes. Moreover, smaller length leads to less number of spectrum slicing without the presence of "0" bit condition.

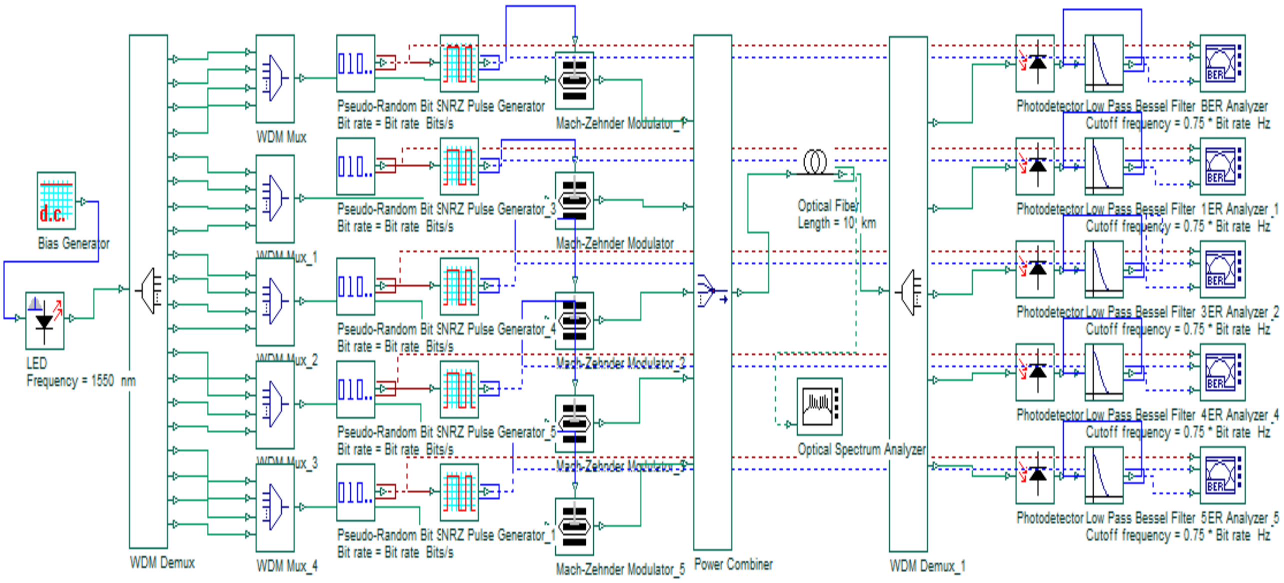

Figure.2 Simulation Schematic Design

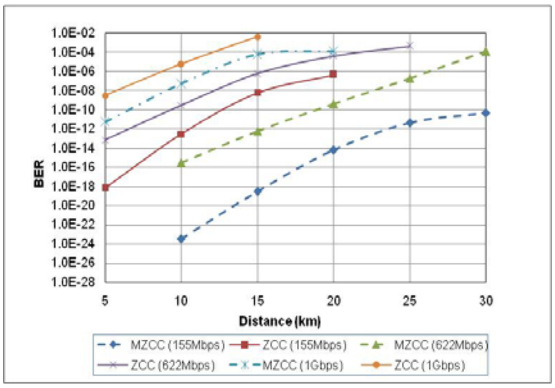

Figure 3: BER versus Distance at different Bit Rate for MZCC and ZCC codes.

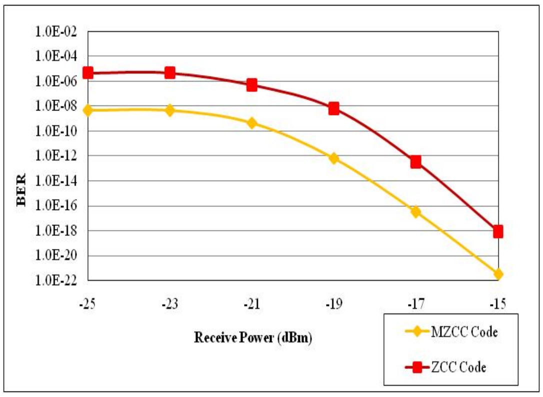

Figure 4: BER versus Receive Power for MZCC and ZCC Code at Bit Rate of 155Mbps

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