Development of a Zero Cross-Correlation Code for Spectral-Amplitude Coding Optical Code Division Multiple Access (OCDMA)

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Summary
A new code structure for Spectral-Amplitude Coding Optical Code Division Multiple Access (OCDMA) system with zero cross-correlation is been proposed in this paper. In contrary to the existing code, Zero Cross-correlation (ZCC) code provides much better performance of Bit Error Rate (BER) due to non-existence of Phase Induced Intensity (PIIN) noise. The newly proposed code can adapt to any variable number of weight and user without any constraint by using transformation and mapping technique respectively. Thus, we demonstrate in theoretically to compare the performance of ZCC code with the existing codes such as Hadamard, Modified Frequency Hopping (MFH) and Modified Double-Weight (MDW) codes. For typical error rate of optical communication system, 10^{-9}, it can accommodate 84 users simultaneously. The results indicate that our code is truly performs better than obtained OCDMA codes and applicable to OCDMA network.

Key words:
Optical Code Division Multiple Access (OCDMA), Zero Cross-correlation (ZCC) code, Phase Induced Intensity (PIIN) noise

1. Introduction

The primary feature that distinguishes OCDMA from other multiple access techniques is the use of so-called orthogonal codes to allow multiple users to utilize the same overlapping spectral range without interfering with each other. In spite of the use of orthogonal codes, the main effect limiting the effective signal-to-noise ratio of the overall system is the interference resulting from the other users transmitting at the same time, which is called Multiple Access Interference (MAI). In OCDMA system, phase induced intensity noise (PIIN) is strongly related to multiple access interference (MAI) due to the overlapping of spectra from different users [1]. The key to an effective OCDMA system is the choice of efficient address codes with good or almost zero correlation properties for encoding the source [4]. This property ensures that each codeword can easily be distinguished from every other address sequence. In other words, we seek to make the MAI insignificant compared to the energy contained in the received information bit [5]. Codes that satisfy this property will allow asynchronous operation of the system and minimize the BER by managing the MAI noise term. In response, new Zero Cross-Correlation (ZCC) codes have been designed to satisfy this property. This paper is organized as follows. In section II we will discuss how the code is been developed theoretically. In section III we next discuss on the comparison and its advantage compared to the other OCDMA codes considering the code weight, number of users and code length. In section IV, we focus on performance analysis of the new code and finally the conclusion in section V.

Manuscript received November 5, 2006.
Manuscript revised December 25, 2006.

2. Construction Of ZCC Code

The new proposed ZCC code is represented in a matrix ***K** X **C*** where ***K*** rows will represent number of users and ***C*** column will represent minimum code length. These matrices have binary coefficients and a basic ZCC code (for weight = 1) is define recursively

for w=1

Z_1 =

	C1	*C2*
K1	**0**	**1**
K2	**1**	**0**

Notice that Z_1 has no overlapping of ‘1’ for both users. In order to increase the number of users and codes, a mapping technique is used as below

$$Z_2 = \begin{bmatrix} 0 & Z_1 \\ Z_1 & 0 \end{bmatrix} =$$

	C1	*C2*	*C3*	*C4*
K1	**0**	**0**	**0**	**1**
K2	**0**	**0**	**1**	**0**
K3	**0**	**1**	**0**	**0**
K4	**1**	**0**	**0**	**0**

From the mapping, it is noted that when the number of users *K* increase, the code length *C* increase as well. The pattern of mapped code is mirror diagonally expanded and *K* is equally increased with *C*. The relation between the number of mapping process *M*, number of users *K* and code length *C* is given by:

$$K = 2^M \quad (1)$$

and

$$C = 2^M \quad (2)$$

thus

$$C = K \quad (3)$$

The ZCC code has flexibility in number of weight consideration. To increase the number of weight, it needs to formulate using few steps so-called 'code transformation' [3]. In ZCC code, the basic code represent weight = 1. To transform the code from *w*=1 to *w*=2, the general form of transformation is given by

$$Z_t = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \quad (4)$$

where

[A] – consist of [1, *w* (*w*-1)] matrix of zero.
[B] – consist of *w* replication of matrix $\sum_{j=1}^{w} j$ [0 1].
[C] – consist of duplication of matrix from $w-1$.
[D] – consist of diagonal pattern with alternate column zeros matrix.
For example the transformation code from $w=1$ to $w=2$ is shown as

$w=1$

	C1	*C2*
K1	**0**	**1**
K2	**1**	**0**

$w=2$

	C1	*C2*	*C3*	*C4*	*C5*	*C6*
K1	**0**	**0**	**0**	**1**	**0**	**1**
K2	**0**	**1**	**0**	**0**	**1**	**0**
K3	**1**	**0**	**1**	**0**	**0**	**0**

The relationship between parameters *K*, *w* and *C* is given by

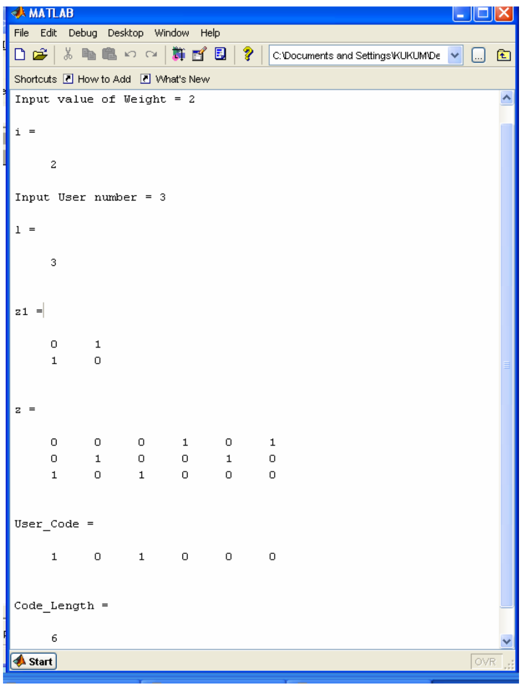
$$K = w + 1 \quad (5)$$

$$C = w(w+1) \quad (6)$$

where

K - number of user
C – code length
w - code weight

Notice that the codeword corresponding to parallel lines are orthogonal to each other. To increase the number of user in simultaneously with the increasing of code weight, we can easily implement the mapping technique as described previously.
This transformation technique can also been written in MATLAB program for the ease of generating the code corresponds to the *K*th user. The code generator is shown as below:



The general formula for generating the ZCC code is given :

$$ZCC_{i,j} = \begin{cases} 1 & if \quad \begin{cases} j = (n_1 - 1) + \left\lfloor {(2n_1 + 1)}/{2} \right\rfloor + \sum_{m=0}^{i \bmod k_{B1} - 2} (2w - 2m) & for \quad n_1 = \{1,2,..,w-(i-1)\} \\ j = 2(i-1) + \sum_{m=1}^{\lfloor n_2 - 1 \rfloor} (2w - 2m) & for \quad n_2 = \{1,2,...,(i-1)\} \end{cases} \\ 0 & Otherwise \end{cases} \quad (7)$$

Basic code length

$$C_B = 2\sum_{m=1}^{w} m \quad (8)$$

Basic number of user

$$K_B = w + 1 \quad (9)$$

where w is the weight of the code with zero cross correlation value.

3. Code Comparison

Many codes have been proposed for OSCDMA such as optical orthogonal codes (OOC) [3], modified double weight (MDW) and modified frequency-hopping (MFH) codes [1]. However, these codes suffer from various limitations one way or another. The codes' constructions are either complicated (e.g., OOC and MFH codes), the cross-correlation are not ideal or the code length is too long (e.g., OOC). Long code length is a disadvantage of ZCC code since either very wide band sources or very narrow filter bandwidths are required.
Table I shows the code length required by the different codes to support only 30 users. For example, if the chip width (filter bandwidth) of 0.5 nm is used, the OOC code will require a spectrum width of 182 nm , whereas, modified double weight (MDW) only requires 45 nm. For ZCC code, it requires 60 nm of spectrum width. MDW and MFH codes show shorter code lengths than that of ZCC code. But compare to OOC, ZCC code is still has a nearly half shorter code length. It will be shown that the transmission performance of ZCC code is significantly better than that of MDW and MFH codes. This is achieved through theoretical calculation.

TABLE I Comparison between OOC, Hadamard, MDW code, MFH and ZCC code.

Codes	**No of user (K)**	**Weight (w)**	**Code Length (C)**
OOC	30	4	364
Hadamard	30	16	32
MDW code	30	4	90
MFH	30	7	42
ZCC code	30	4	120

4. Performance Analysis

Considering multiple users, the difference of chip power will lead to the produce of errors after combined several times [2]. By using ZCC code, this problem has been eliminated. Here, we analyze the BER of the system with assumption that only considering MAI with Shot Noise and Thermal Noise, ignoring the Phase Intensity Induced Noise (PIIN).
Signal-to-noise ratio (SNR) of ZCC code is calculated by using this formula [3]:

$$SNR = \frac{\left(\frac{RP_{sr}k}{N}\right)^2}{eBRP_{sr}\frac{w+k-1}{N} + \frac{4k_B T_r B}{R_L}} \quad (10)$$

$$BER = \frac{1}{2} erfc\sqrt{\frac{SNR}{8}} \quad (11)$$

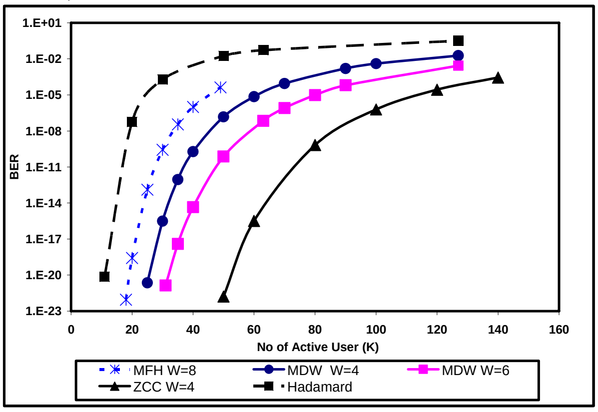
where

R - photodiode responsivity
P_{sr} - effective power at receiver
e - electron charge
B - electrical equivalent noise band-width of the receiver
k_B - Boltzmann's constant
T_r - temperature of receiver noise
R_L - load resistance
w - weight
k - no. of user
C - code length

and $erfc$ is a complementary error function $erfc(x) = \frac{2}{\sqrt{\pi}} \int_x^{\infty} e^{-u^2} du$

Base on equation (10) and (11) respectively, the results of BER are shown in figure 1. Note that Figure 1 shows a significantly better performance of ZCC code compared to Hadamard, MDW and MFH codes. The graph also shows that at typical bit error rate for optical communication system ranges from 10^{-9} to 10^{-12}, 72 to 84 users can be used simultaneously.

Figure 1 Performance Comparison between Hadamard, MDW, MFH and ZCC codes.



This is because of the superior code properties of ZCC code, such as cross-correlation that is always equal to zero. It is clear that the system using ZCC codes have much lower BER than the one using MFH and MDW codes, although the code weight for, MFH and MDW codes are higher than ZCC codes. OOC was not taken into consideration to this performance analysis due to high code length.

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5. Conclusion

Codes with ideal cross-correlation have been studied for many years [4]. The performance of the OCDMA system is degraded as the number of simultaneous users' increases, especially when the number of user is large. This is attributed to the multiple access interference (MAI) which arises from the incomplete orthogonal of the used signature codes.

In this paper, the zero cross-correlation code has been constructed in simple algebraic ways. The great contribution of this code is the elimination of PIIN and it has been shown that performance can be improved significantly when there is zero correlation between the codes. Analytical results reveal that ZCC code not only performs better on BER compared to OOC, MFH and MDW codes. Consequently, ZCC code is very suitable for use in OCDMA access systems and provides an additional choice in OCDMA scheme.

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