Random Diagonal code for Spectral Amplitude-Coding Optical CDMA system

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Summary
A new code structure for spectral amplitude coding optical Code Division Multiple Access (CDMA) system is constructed using " RD" code (Random Diagonal) the new code which can be constructed using address level and data level, provides better performance of Bit Error Rate (BER) due to non-existence of Phase induced Intensity Noise (PIIN) at data level, which means that zero cross correlation at data level are always exist, therefore compared with MFH code and MDW code, this new code exist for much wider number of integers, and hence we can choose a code with the desired length more freely. Theoretical analysis result shows that for typical error rate 10^{-15}, it can accommodate 200 users simultaneously. The result indicate that our code is truly performs and applicable to OCDMA network.

Key words:
Optical Code Division Multiple Access (OCDMA), Multiple Access Interference (MAI), Phase Intensity Induced Noise (PIIN), Signal-Noise Ratio (SNR).

1. Introduction

In all types of optical code division multiple access (CDMA) systems, spectral amplitude-coding systems have received more attention in recent year for application in optical access network since multiuser interference can be eliminated when a code with fixed inphase cross correlation (such as m-sequence code or Hadamard code) is used [1]. OCDMA is a spread-spectrum broadcast technique in which each user of the network is allocated a unique optical code (address) sequence with good correlation properties, consisting of unipolar signals. [2]. This code can be used to label data bits broadcast onto the network that are intended for receipt by a particular user, or alternatively to label bits that have been sent from a particular user. This approach also provides a high level of security since information to be transmitted is optically encoded in the physical layer of the network.

OCDMA is useful for short haul optical networking because it can support both wide and narrow bandwidth applications on the same network, permits quality of service guarantees to be managed at the physical layer, offers robust signal security and has simplified network topologies. In other words, we seek to make the MAI insignificant compare to the energy contained in the received information bit[3] Equally exciting, is the way OCDMA simplifies the management of large numbers of users by requiring minimal network control and reconfiguration. Relieved of the cost and complexity of coordinating and switching dozens of separate wavelengths, an OCDMA network's switching function is performed by the distribution of codes.The main issue of the studies on the OCDMA networks is to devise a code set of good system performance. In unipolar optical code based OCDMA systems, the system performance is determined by the bandwidth efficiency of the optical codes which is closely related with the error probability behavior of the optical code in multiple user circumstance. The code set size dependence on the code length. For the OCDMA scheme to be more realistic, it is desired to devise an optical code that can accommodate a larger number of simultaneous users with a low error probability for a given code length. [4]. A good set of code is to obtain the maximum number of codes with maximum weight and minimum length with the best possible autocorrelation and cross-correlation properties. A code with a larger size should give better BER performance. Hence unipolar {0,1} codes which have low out-of-phase autocorrelation and cross-correlation values are used. This paper is organized as follows. In section II we will discus how the code is been develop theoretically and its properties. In section III, we focus on performance analysis of the new code and finally the conclusion in section IV.

2. Code construction and code properties

We denotes a code by (N, W, λ) where N is the code length, W is the code weight, and λ is it in-phase cross

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correlation. Let us define $\lambda = \sum_{i=1}^{N} x_i y_i$ as the inphase cross correlation of two different sequences $X=(x_1,x_2,\ldots x_N)$ and $Y=(y_1,y_2,\ldots y_N)$. When λ=1, it is considered that the code possess ideal inpahse cross correlation. The design of this new code can be preformed by dividing the code sequence into two group which is code level and data level.

Step1: data level, let the elements in this group contain only one "1" this properties is important to keep cross correlation zero at data level. Thus the data level proposed zero cross correlation ($\lambda = 0$), this properties is represented in a matrix (K x K) where K represent number of users. the matrices have binary coefficient and a basic Zero cross code (weight=1) are defined as Y. For example three users (K=3), Y can be expressed as

$$Y_1 = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{bmatrix}$$

Where $[Y_1]$ –consist of (K $\times$K) diagonal ones "1"
Notice, for above expression the cross correlation between each element on row is always zero.

Step2: code level, the matrix representation of this matrix can be expressed as follow for W=4

$$Y_2 = \left[\begin{array}{ccc:cc} 1 & 1 & 0 & 1 & 0 \\ 0 & 1 & 1 & 0 & 1 \\ 1 & 0 & 1 & 1 & 0 \end{array}\right]$$

Where $[Y_2]$ – consists of two main matrix parts basics matrix which called **B** matrix

$$[B] = \begin{bmatrix} 0 & 1 & 1 \\ 1 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix},$$

And weight part which called **M** matrix $[M_1] = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 0 \end{bmatrix}$

which is responsible for increasing number of weights, let $M_i = [M_1 \ M_2 \ M_3 \ \ldots M_i]$, where i represents number of [M] matrix on matrix M_i, given by

$$i = (W-3)$$

for example if W=5, from Eq.(1) i=2, so that $M_2 = [M_1 \ M_2]$

$$[M_2] = \begin{bmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ 1 & 0 & 1 & 0 \end{bmatrix}$$

Notice that to increase the number of user in simultaneously with the increase of code word length we can just repeat each row on both Matrixes [M] and [B], on the other word for K-th users matrix [M] and [B] can be expressed as

$$M(j) = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 0 & 1 \\ : & : \\ : & : \\ a_{j1} & a_{j2} \end{bmatrix}, \quad \text{and} \quad B(j) = \begin{bmatrix} 0 & 1 & 1 \\ 1 & 1 & 0 \\ 1 & 0 & 1 \\ 0 & 1 & 1 \\ 1 & 1 & 0 \\ : & : & : \\ : & : & : \\ a_{j1} & a_{j2} & a_{j3} \end{bmatrix}$$

Where j represent the value for K-th users (j=1,2…K), and the value of a_j is either zero or one. The weight for code level for both matrix [M], [B] are equal to W-1, so the total combination of code is represent as (K$\times$N) where K=3, N=8, as given by $[Z_1]$, $(Z_1 = Y_1 \mid Y_2)$

$$Z_1 = \begin{bmatrix} 0 & 0 & 1 & 1 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 1 & 1 & 0 & 1 \\ 1 & 0 & 0 & 1 & 0 & 1 & 1 & 0 \end{bmatrix}$$

from the above basic matrix Z, determines the number of users (K) and the code length (N), as given by (K$\times$N) matrix. Notice that the code weight of each row is equal 4, the relation between N and K for this case (W=4) can be expressed as

$$N = k + 5 \qquad (2)$$

As a result we can found that for W=5,6, and 7 code word length N can be expressed as $K+7$, $K+9$ and K+11 respectively. As a results the general equation describing number of users K, code length N and code weight W is given as

$$N = K + 2W - 3 \quad (3)$$

As an example, to get a large number of users, say K=6 for W=4, the matrix is given by

$$Z_2 = \left[\begin{array}{cccccccc:ccc} 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 1 \end{array}\right]$$

From above matrix, for K=6, resulting N= 11 [using Eq. (3)]. Also the cross correlation between any rows is always equal to one.

In term of code length (N), RD code offers better performance than MFH and MDW code in term of code length for same number of users as shown in Table(1). For example, if chip width (filter bandwidth) of 0.6 is used, the MWD will require a spectrum width of 261 nm whereas, RD code only require 102 nm , for MFH code its requires 109 nm of spectrum width. RD code show shorter length than other code, thus too long code length is considered disadvantage in implementation since either a very wide band sources or very narrow filter bandwidths are required. On the other hand too short a code may not be desired because limit the flexibility of the code.

Table 1. Comparison between RD, MFH, and MDW code.

Code	***No.of user***	**weight**	***Code lenght***
RD	145	14	170
MFH	145	14	182
MDW	145	4	435

3. System performance Analysis and code comparison

In the analysis of the proposed code we have considered incoherent intensity noise, as well as shot noise and thermal noise, but since the proposal code due to the use of a broadband thermal source, a new noise signal is generated. This noise is referred to as the phase-induced intensity noise (PIIN) and it becomes the major factor of system performance degradation. To suppress its effect, RD codes with ideal in-phase cross correlation systems, the inherent phase-induced intensity noise (PIIN) also severely affects the overall system performance [5]. This noise is due to spontaneous emission of the broadband source. By using RD codes the problem for PINN has been eliminated the only considering MAI with shot noise and thermal noise, ignoring the phase Intensity Induced Noise (PIIN).

Signal-to-noise ratio (SNR) of the proposal code is calculated by using formula [6]

$$SNR = \frac{\left(\frac{RP_{sr}W}{N}\right)^2}{eBRP_{sr}\frac{W+K-1}{N} + PIIN + \frac{4K_BT_rB}{R_L}} \quad (4)$$

$$BER = \frac{1}{2}erfc\sqrt{\frac{SNR}{8}} \quad (5)$$

R -Photodiode responsively
P_{sr} -effective power at receiver
e -electron charge
B - electrical equivalent noise band-width of the reciver
K_B - Boltzmans constant
T_r - Temperature of receiver noise
R_L - load resistance
W - weight
K -No. of user
And *erfc* is a complementary error function.

Base on equation (4) and (5) respectively, the result of BER are shown in figure(1) , the system parameters are P_{sr} = -10dBm, R_L =1030 ohms, photodiode quantum efficiency is 0.6 and electrical bandwidth B= 80 MHz . Figure(1) illustrate the variation of BER with various number of users assuming MFH code and MWD code schemes, from this figure it has been clearly shown that RD code results in a much better performance than MFH and MDW codes, this result can be explained as follow the effect of PIIN is zero since cross correlation at data level is equal to zero.

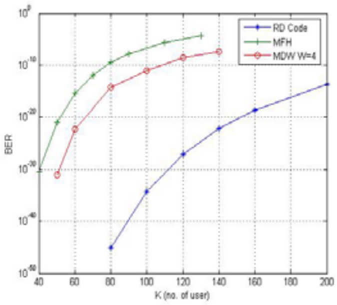

Fig.1 BER versus number of simultaneous user when Psr=-10dBm

Fig.1 depicts the BER variation with Psr when the number of simultaneous users is 145, investigating this figure reveals that when the Psr above -15dBm the BER approaches approximately constant level, in this region the BER become almost insensitive, and as a result the BER response for RD is better than MFH for same number of users.

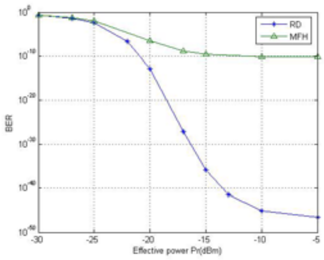

Fig. 2 BER versus effective power Psr, when number of simultaneous users is 145

4.Conclusion

In this paper, we have proposed a series of new code families called RD code with in-phase cross correlation value of one at code level, and zero at data level. The advantages of this code can be summarized from simulation results as follow: shorter code length, No cross-correlation in data level, Zero cross-correlation will minimized the λ and reduce PIIN (Phase Induced Intensity Noise), Data level can be replaced with any type of codes, More overlapping chips will result in crosstalk, and finally flexibility in choosing N, K parameter than other code like MFH and MDW codes. It has been shown that through simulation results RD code get better BER performance than others code mentioned above because this code deal with zero cross correlation for suppressing the intensity noise and improved the overall system performance, so a result this code can also be used in synchronous optical CDMA system for the cancellation of MUI.

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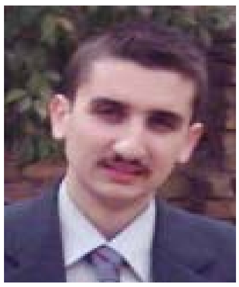

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