Performance of Random Diagonal Codes for Spectral Amplitude Coding Optical CDMA Systems

Hilal A. Fadhil, Syed A. Aljunid, and R. Badlishah Ahmed

Abstract—In this paper we study the use of a new code called Random Diagonal (RD) code for Spectral Amplitude Coding (SAC) optical Code Division Multiple Access (CDMA) networks, using Fiber Bragg-Grating (FBG), FBG consists of a fiber segment whose index of reflection varies periodically along its length. RD code is constructed using code level and data level, one of the important properties of this code is that the cross correlation at data level is always zero, which means that Phase intensity Induced Phase (PIIN) is reduced. We find that the performance of the RD code will be better than Modified Frequency Hopping (MFH) and Hadamard code It has been observed through experimental and theoretical simulation that BER for RD code perform significantly better than other codes. Proof –of-principle simulations of encoding with 3 channels, and 10 Gbps data transmission have been successfully demonstrated together with FBG decoding scheme for canceling the code level from SAC-signal.

Keywords—FBG, MFH, OCDMA, PIIN, BER.

I. INTRODUCTION

OPTICAL code division multiple access has been recognized as one of the most important technologies for supporting many users in shared media simultaneously, and in some cases can increase the transmission capacity of an optical fiber[1], by assigning unique random optical code, is attractive for next generation broadband access networks due to its features of allowing fully asynchronous transmission with low latency access, soft capacity on demand, as well as simplified network argument [2~4]. The assumption of large code space does not always hold in practice, especially for the spectral-phase-encoded O-CDMA [5-6]. Because of optical hardware limitations and the code orthogonality required for low multiple access interferences, feasible spectral-phase-encoding solutions are limited to several well-known code families that contain relatively small number of codes. The spectral-phase-encoded OCDMA network exploits relatively simple all-optical pulse shaping to achieve optical encoding and decoding. In this scheme, the entire pulse spectrum is divided into different spectral components called "chip." The number of "chips" is chosen to be the length of the selected code. Across the spectrum, the phase is altered in each chip according the phase code.

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. 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[7]. To establish the optical CDMA, we have to overcome the code orthogonality problem. Many researchers have proposed several codes such as prime code, optical orthogonal code, and so on. In this paper, we focus on RD codes among those codes. In section II, we introduce the RD code construction and how the code is been develop theoretically and its properties. In Section III we focus on the proposed system scheme and design steps and finally the conclusion is in section IV.

II. RD CODE DEVELOPMENT

An (N, W, λ) RD code is a family of (0,1) sequence of length N, weight W and λ is the in-phase cross correlation which satisfy the following two properties: 1- Zero cross-correlation will minimized the λ and reduce PIIN (Phase Induced Intensity Noise) 2- No cross correlation in data level. The design of this new code can be preformed by dividing the code sequence into two groups which are code level and data level.

Step A: 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 will represent number of users these matrices have binary coefficient and a basic Zero cross code (weight=1) is defined as Y, for example three users (K=3), Y can be expressed as

Where $[Y_1]$ –
$$Y_1 = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{bmatrix}$$
consist of (K $\times$ K)

Hilal Adnan Fadhil is with the School of Computer and Communication, University Malaysia Perlis, 02000 Kuala Perlis, Perlis, Malaysia (e-mail: eng_hilal_adnan@yahoo.com).

Syed A. Aljunid, and R.Badlishah Ahmed are with the School of Computer and Communication, University Malaysia Perlis, 02000 Kuala Perlis, Perlis, Malaysia (e-mail: syedalwee@unimap.edu.my, e-mail: badli@unimap.edu.my).

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diagonal ones "1".
Notice, for the above expression the cross correlation between each element on row is always zero

Step B: code level, the matrix representation of this matrix can be expressed as follows for W=4

$$Y_2 = \begin{bmatrix} 1 & 1 & 0 & \vdots & 1 & 0 \\ 0 & 1 & 1 & \vdots & 0 & 1 \\ 1 & 0 & 1 & \vdots & 1 & 0 \end{bmatrix}$$

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 $M_i=[M_1 \ M_2 \ M_3 \ ....M_i]$, where i represents number of [M] matrix on matrix M_i, given by

$$i= (W-3) \qquad (1)$$

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

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

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×N) where K=3, N=8,

as given by $[Z_1]$, $(Z_1=Y_1| \ Y_2)$

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

from the above basic matrix Z, determines the number of users (K) and the code length (N), as given by (K×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

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

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

$$Z_2 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 1 & \vdots & 1 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & \vdots & 0 & 1 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 & 0 & \vdots & 1 & 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & \vdots & 1 & 1 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 & 0 & \vdots & 0 & 1 & 1 & 1 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & \vdots & 1 & 0 & 1 & 0 & 1 \end{bmatrix}$$
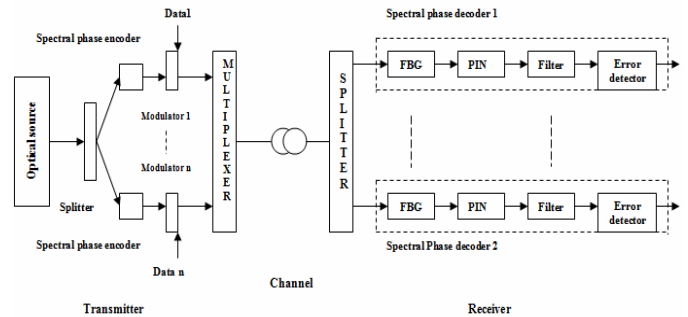

Fig. 1 Simulation setup of the proposed encoding/decoding scheme

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

Many codes have been proposed for OCDMA systems, such as optical orthogonal code (OOC), modified frequency – hopping (MFH) codes, and Hadamard code, but the key points of RD code is that the code length (N), RD code offers better performance than other codes in term of code length for same number of users, K, of 30 as shown in Table I. Short code length limit the addressing flexibility of the codes, while long code length are considered disadvantage in implementation, since either very wide –bandwidth source or very narrow filter

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bandwidth are required, RD codes exists for practical code length that are neither too short nor too long.

TABLE I
COMPARISON BETWEEN RD, MFH, OOC, HADAMARD, AND PRIME CODES
FOR THE SAME NUMBER OF USERS K = 30

Code	No. of user K	Weight W	Code length N
OCC	30	4	364
Prime code	30	31	961
Hadamard	30	16	32
MFH	30	7	42
RD code	30	3	33

III. PERFORMANCE ANALYSIA

Fig. 1 shows the setup of the proof-of- principle simulation for the proposed scheme. The performances of RD, MFH, and Hadamard codes are simulated by using the simulation software OptiSystem Version 6.0. A simple schematic block diagram consists of two users, as illustrated in Fig. 1. Each chip has a spectral width of 0.8 nm. The tests were carried out at a rate of 10 Gb/s for 20-km distance with the ITU-T G.652 standard single-mode optical fiber. All the attenuation α (i.e., 0.25 dB/km), dispersion (i.e., 18 ps/nm km), and nonlinear effects were activated and specified according to the typical industry values to simulate the real environment as close as possible. The performances of the system were characterized by referring to the bit-error rate (BER). As shown in Fig. 1 after transmission, we used a Fibre Bragg grating (FBG) spectral phase decoder operates to decode the code at data level, the decoded signal were decoded by a photo-detector (PD) followed by a 0.75 GHz low-pass-filter (LPF) and error detector respectively. The transmitted power used was 0 dBm out of the broadband source. The noise generated at the receivers were set to be random and totally uncorrelated. The dark current value was 5 nA, and the thermal noise coefficient was 1.8×10^{-23} W/Hz for each of the photodetectors. The eye pattern diagrams for RD, Hadamard and MFH codes are shown in Fig. 2 respectively.

The maximum input power that we can launch into the fiber is limited. This also limits the maximum transmission distance, L. If P_{inMAX} is the maximum input power, the transmission distance is L, and Pr is the minimum receiver power; then Eq.(4) shows the maximum input power that can be sent into the fiber.

$$P_{inMAX}(dB) = \alpha L + P_r(dB) \qquad (4)$$

The optical power at the receiver end has to be within the dynamic range of the receiver; otherwise, it damages the receiver (if it exceeds the maximum value) or the receiver cannot differentiate between 1s and 0s if the power level is less than the minimum value. This is given by the dynamic range of the receiver, and it sets the maximum and minimum power range for the receiver to function. For OCDMA, −7 dBm to −28 dBm is a typical dynamic range of a receiver[8].

Using Eq.(4) we can find the maximum transmission distance for the proposed scheme without amplification which is equal to 40 Km. The eyes diagram shown in Fig. 2 clearly depict that the RD code system gives better performance, having a larger eye opening the corresponding simulated BER for RD, Hadamard, and MFH codes systems are shown in Fig.2 the vertical distance between the top of the eye opening and maximum signal level gives the degree of distortion. The more the eye closes, the more difficult it is to distinguish between 1s and 0s in the signal. The height of the eye opening at the specified sampling time shows the noise margin or immunity to noise [9].
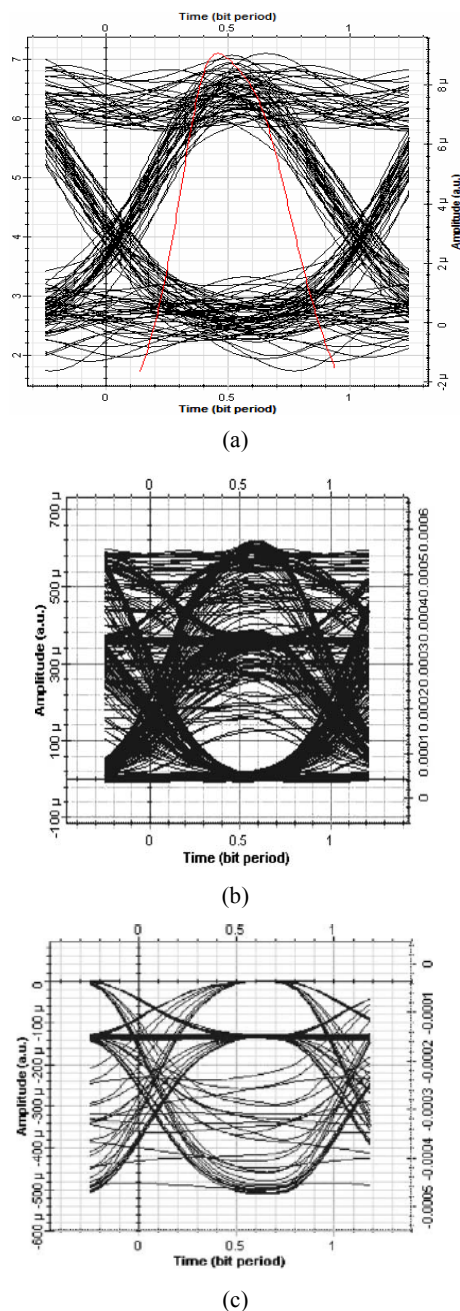

(a)

(b)

(c)

Fig. 2 Eye diagram of (a) one of the RD channels, (b) one of the Hadamard channels, and (c) one of the MFH channels, at 10 G bit/s

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Using the general equation that was used in a previous report [10], Fig. 3 shows BER versus number of users for the different codes. For these results the following parameters were used: line width thermal noise = 3.75×10^{12} Hz, electrical bandwidth = 750 MHz at the operating wavelength of 1550 nm. The figure clearly shows that the BER for RD code is better than other code as well as can support more user than MFH code.
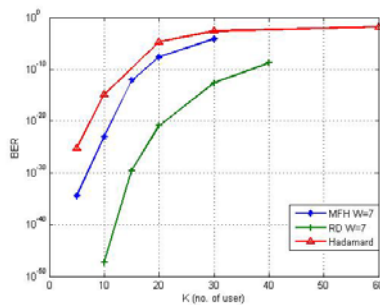

Fig. 3 BER against number of users for RD, Hadamard, and MFH codes when P_{sr}= 0 dBm

IV. CONCLUSION

The predominance of OCDMA spectral –amplitude –coding is distinct because its requirement to light source is not strict and its encoder/ decoder using FBGs is simple to be implemented. With the RD code the system has eminent correctively which can efficiency reduces the BER of the system and good performance of the system can be ensured. It has been shown that the RD code performs better than the system encoder with MFH and Hadamard and the advantages of the proposed code are: shorter code length, No cross-correlation in data level (zero cross-correlation will minimized the λ and reduce PIIN), 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. The simulated result of one of the three RD coded carriers running at 10 Gb/s over a communication-standard fiber shows a good quality transmission at the BER of 10^{-13}.

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Hilal A. Fadhil received the B.Sc. From Al-Nahrain University (Saddam university) in Electronics' and communications engineering, Baghdad-IRAQ 2002, and the M.Sc. degree in Communication Engineering from Al-Nahrain university in 2004, his research interest are on wireless communications networks, optical communications, and he is currently working toward Ph.D degree in optical communications, working on Optical Code-Division-Multiple Access (OCDMA) networks, at university Malaysia Perils department of computer and communication engineering/ Malaysia.

Syed Alwee Aljunid received the BEng in computer and communication systems _first-class honors_ and the PhD in Communication and network engineering from Universiti Putra Malaysia in 2001 and 2005, espectively. He is currently an associate Professor in the School of Computer and Communication Engineering, University Malaysia Perlis College of Engineering _UniMAP_, Perlis, Malaysia. His research interests include OCDMA technologies and wavelength division multiplexing.

R. Badlish Ahmad obtained B.Eng in Electrical & Electronic Engineering from Glasgow University/UK in 1994. He continued his M.Sc study in Optical Electronic Engineering at University of Strathclyde / UK and graduated In 1995. He then continues his study at PhD level at the same university and completed in 2000. His research interests are on computer and telecommunication networks. He is currently the Dean at the School of Computer and Communication Enginering "University Malaysia Perlis" and the pioneer in integrating courses using open source software in the engineering degree program.