Performance of OCDMA Systems Using Random Diagonal Code for Different Decoders Architecture Schemes

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Abstract: *In this paper, new code families are constructed for spectral-amplitude coding optical code division multiple access, called random diagonal code for spectral amplitude coding optical code division multiple access networks. Random diagonal 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 Noise is reduced. We find that the performance of the random diagonal code will be better than modified frequency hopping and Hadamard code. It has been observed through simulation and theoretical calculation that bit-error rate for random diagonal code perform significantly better than other codes. We analyze the performance of the proposed codes and examine how the code size and correlation properties are related. Three different decoding schemes are used for implementing the system: thin film filter, arrayed waveguide grating and Fiber Bragg Grating. Simulation results show that for low channel (three users), the thin film and AWG filters perform well but Fiber Bragg Grating filters have higher dispersion than others, which could reduce the goal of 10 Gbit/s channel.*

Keywords: *Optical code division multiple access, bit-error rate, phase intensity induced noise, SNR, and modified frequency hopping.*

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1. Introduction

Optical Code Division Multiple Access (OCDMA) technique is a promising solution for optical network since it allows users to access the network asynchronously and provides flexible and secure transmission. In earlier OCDMA systems, optical codes using time spreading techniques were adopted originally [3]. To eliminate the Multiple Access Interference (MAI), a few researchers proposed the use of spectral-phase coding to obtain the orthogonality of bipolar codes by programming the phase 0 and 180 degrees. Since phase coding was very difficult to preserve in fiber, the technique of SAC with unipolar versions of the same bipolar code was proposed [4]. SAC schemes operates at bit rate, thus the requirement for receiver bandwidth is relaxed. Since low cost broadband source and detector can be used for network implementation, the cost for end users is more economical. Many codes have been proposed for OCDMA such as Optical Orthogonal Codes (OOCs) [1], prime codes, and Modified Frequency Hopping (MFH) codes [8].

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 (e.g., Hadamard and Prime codes), or the code length is too long (e.g., OOC and Prime code). Long code lengths are considered disadvantageous in its implementation since either very wide band sources or very narrow filter bandwidths are required. There are a number of different techniques to implement OCDMA. One technique is where a broad band of light is used, and the spectral amplitude of a source is modulated with Random Diagonal (RD) code that specifies certain components of the spectrum to be one and off. In such a network, different transmitters use different codes. The receiver can then select the data from the desired transmitter by correlating the spectral modulated signal with appropriate code; it can detect each wavelength band separately, and then the correlation function is performed electronically. Fiber Bragg Gratings (FBGs), thin film filter, and AWGs can be used as the main part in the corresponding coder/ decoder implementations [9, 7]. These filters have been tested to assess the suitability of these filter types as decoding devices in OCDMA networks using RD code. In this study, we construct a series of new RD code families, and then we design the structure of both the transmitter and the receiver with different decoder schemes. Finally, the eyes diagram and the bit error rate of our system is evaluated and compared with other codes.

2. Code Construction and Code Properties

Many OCDMA strategies have been proposed [8, 9], where one of the major concerns of designing RD code sequences is MAI because the performance of such system is usually interference limited. However, due to the characteristics of optical signals, in the direct detection OCDMA system the signature sequence consists of unipolar (0, 1) sequences. We denote a code by (N, W, λ), where N is the code length, W is the code weight, and λ is in-phase cross correlation. Let us define $\lambda = \sum_{i=1}^{N} x_i y_i$ as the in phase cross correlation of two different sequences $X=(x_1, x_2, \ldots x_N)$ and $Y=(y_1, y_2, \ldots y_N)$. When $\lambda=1$, it is considered that the code possess ideal in phase cross correlation. The design of this new code can be preformed by dividing the code sequence into two groups, which are code segment and data segment.

- Step 1: *data segment*: let the elements in this group contain only one "1" to keep cross correlation zero at data level ($\lambda = 0$). This property is represented by the matrix ($K \times K$) where K will represent number of users. These matrices have binary coefficient and a basic Zero cross code (weight=1) is defined as $[Y_1]$. For example, three users ($K=3$), $y(K \times K)$ can be expressed as

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

  where $[Y_1]$ –consists of ($K \times K$) identity matrices. Notice, for the above expression the cross correlation between any two rows is always zero.

- Step 2: *code segment*: the representation of this matrix can be expressed as follows 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 parts -weight matrix part and basics matrix part. Basic part [B] can be expressed as:

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

  And weight part called M matrix can be expressed as:

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

  which is responsible for increasing number of weights. Let $i=(W-3)$ and $M_i=$

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

where i represents number of M_i matrix on matrix [M], given by

$$[M]=\langle M_1 | M_2 | M_3 \ldots\ldots M_i \rangle \tag{1}$$

For example, if $W=5$, from equation 1, $i=2$, so that $[M]=\langle M_1 \mid M_2 \rangle$

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

Notice that to increase the number of users simultaneously with the increase of code word length we can just repeat each row on both Matrixes [M] and [B]. For K^{th} user 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 represents the value for K^{th} user ($j=1,2\ldots K$), and the value of a_j is either zero or one. The weights for code part for both matrix [M], [B] are equal to $W-1$, so the total combination of code is represented as $(K \times N)$ where $K=3$, $N=8$, as given by [Z], $[Z]=[Y_1|Y_2]$

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

From the above basic matrix Z, determine 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 to 4, and the relation between N and K for this case ($W=4$) can be expressed as

$$N=K+5 \tag{2}$$

As a result we can find 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 result the general equation describing number of users K, code length N and code weight W is given as

$$N = K + 2W - 3 \tag{3}$$

Finally, using the properties of RD code, the SNR for RD code is derived mathematically as follow:

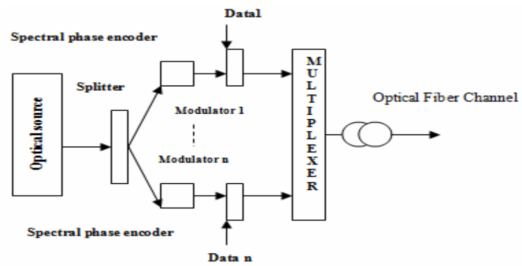
$$SNR = \frac{\left(\frac{2\Re P_{sr} W}{N}\right)^2}{\frac{2eBWP_{sr}\Re}{N} + \frac{B\Re^2 P_{sr} W K}{2N^2 \Delta V}(K-1+W) + \frac{4K_B T_n B}{R_L}} \tag{4}$$

where, $\Re$ represents photodiode responsively, *Psr*-effective power at receiver, *e* -electron charge, *B*-electrical equivalent noise band-width of the reciver, K_B - Boltzmans constant, *Tr* - Temperature of receiver noise, *RL* - load resistance. The Bit-Error Rate (BER) can be calculated using Gaussian approximation [2]

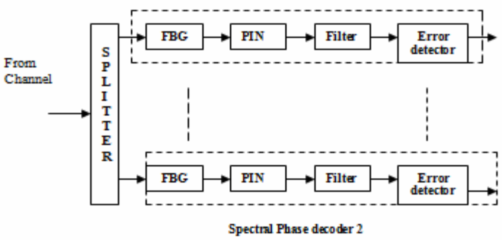
$$BER = \frac{1}{2} erfc \sqrt{\frac{SNR}{8}} \tag{5}$$

3. System Performance Analysis

The network architecture of the optical CDMA system using RD code is shown in Figure 1. Each of the users will encode the data with a different OCDMA code word and broadcast it to all the receivers. 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 Figure 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 BER. As shown in Figure 1, after transmission, we used an FBG spectral phase decoder for decoding the code at data level, the decoded signal were decoded by a Photo-Detector (PD). In the theoretical analysis of the proposed code to find BER, we have considered Phase Induced Intensity Noise (PIIN), as well as shot noise, and thermal noise.



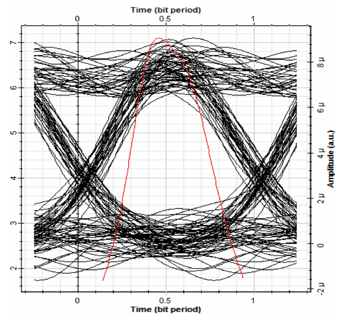
(a) Transmitter.



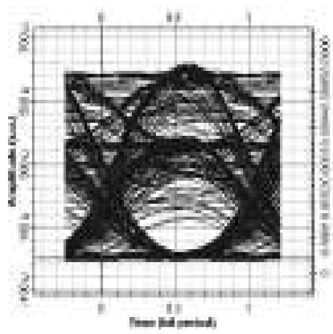
(b) Receiver.

Figure 1. Simulation setup of the proposed scheme.

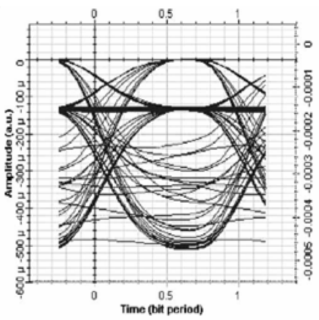
The eye diagrams shown in Figure 2 clearly depict that the RD code system gives a better performance, having a larger eye opening. The corresponding simulated BER for RD, Hadamard, and MFH codes systems are shown in Figure 2. The vertical distance between the top of the eye opening and the maximum signal 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 [5].



(a) One of the RD channels.



(b) One of the Hadamard channels.



(c) One of the MFH channels, at 10 G bit/s.

Figure 2. Eye diagram.

Using the general BER equation for RD code, Figure 3 depicts the relation between the number of users and the BER, for RD, MFH, and Hadamard codes, where they have been plotted for different values of *K* (number of users). For these results the following parameters were used: line width thermal noise = 3.75×10^{12} Hz; electrical bandwidth = 80 MHz at the operating wavelength of 1550 nm. This figure clearly shows that RD code results in a much better performance, i.e., smaller BER than MFH code and Hadamrad code schemes. This is evident from the fact that RD code has a zero cross-correlation while Hadamard code has increasing value of cross-correlation as the number of users increases. Note also that the calculated BER for RD was achieved for *W*=7 while for MFH and Hadamard codes were for *W*=14 and *W*=64, respectively.

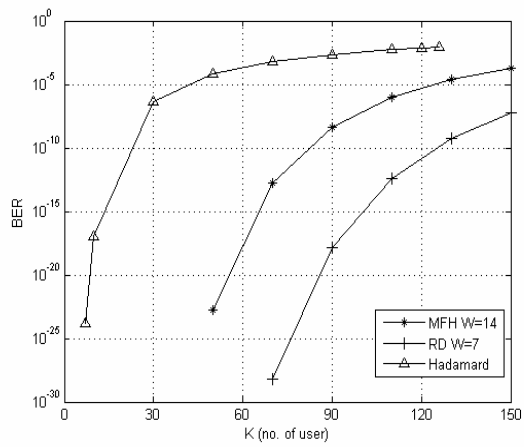


Figure 3. BER versus number of users for RD, MHF, Hadamard codes using P_{sr}= 0 dBm.

Figure 4 shows the BER performance comparison between thin film, AWG, and FBG filters. The thin film filters are known to have a butterworth response and are commonly modeled as 3rd order butterworth filters. AWG filters are modeled using a since response. From the figure we can clearly see that the performance of an optical network will depend on both the amplitude and phase response of the filter used in the optical elements. The response of the FBG and thin film filters are similar and much sharper than of the AWGs. The results also show that BER decreases as fiber length decreases. In addition, thin film and AWG filters show better performance than FBGs because, improving the steepness of the amplitude response of FBG, will result in increasing the dispersion of the filter [6].

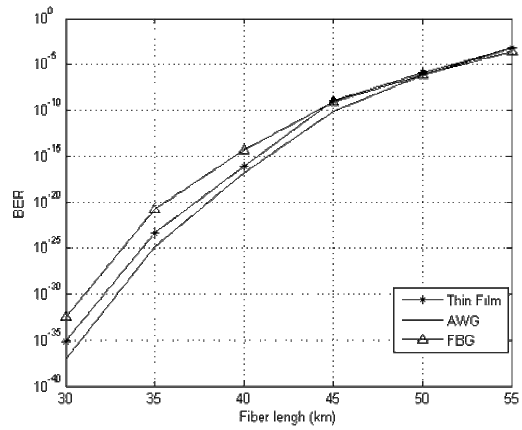


Figure 4. Simulation BER performance for different decoding scheme.

4. Conclusions

We have tested AWG, FBG and thin film filters to assess the suitability of these filter types as decoding devices in OCDMA networks using RD code. FBG filters have higher dispersion than AWG or thin film filters. Thin film filters and AWGs both have low dispersion. Thin film filters have better filter amplitude response leading to lower bandwidth reduction, while FBG filters have higher dispersion which could reduce the goal of 10 Gbit/s channels in RD code scheme. The properties of this code are described and discussed with the related equations. Based on the equations the results of system performance are presented.

To conclude, the advantages of the code can be summarized as follows:

1. Shorter code length.
2. No cross-correlation in data level which minimized λ and reduced PIIN.
3. Data level can be replaced with any type of codes.
4. More overlapping chips will result in more crosstalk.
5. Flexibility in choosing *N*, *K* parameters than other codes like MFH and MDW codes.

The performance of the system with the proposed RD code is analyzed by taking into account the effect of the intensity noise, shot, and thermal noise sources. It is evident that RD code is the best in terms of BER compared to MFH code.

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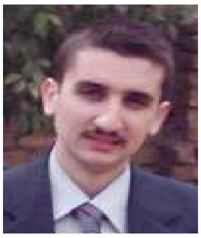

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