

Triple-play Services using Random Diagonal Code for Spectral Amplitude Coding OCDMA Systems

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Summary

In this paper, a new code called Random Diagonal (RD) code for spectral amplitude coding optical code division multiple access (OCDMA) networks is presented. This code is compared with other codes like MQC, MFH and Hadamard which use the same technique. In our work, we utilized this code in one of the OCDMA applications which is called “triple-play” services (audio, video, and data) with different quality-of-service (QoS) requirements; this service is performed by using multiple weights of RD code. The results characterizing the bit-error-rate (BER) with respect to the total number of active users show that RD code offers a significant improved performance over other types of codes. Furthermore, this code can accommodate 20 additional users with smaller code weight at BER of 10^{-9} . In variable weight system, we have shown that using this type of system does not only suppress the Phase Intensity Induced Noise (PIIN), but also that RD code with large weight always have the best performance, when other users of different weights are present in the system.

1 Introduction

Multiple-access techniques are required to meet the demand for high-speed, large-capacity communications in optical networks, which allow multiple users to share the fiber bandwidth. There are three major multiple access approaches. Each user is allocated a specific time slot in time-division multiplexing (TDM) and a specific frequency (wavelength) slot in wavelength-division multiplexing (WDM). Both techniques have been extensively explored and utilized in optical communication systems [1, 2]. Alternatively, OCDMA [3–7], [4] is receiving increasing attention due to its potential for enhanced information security, simplified and decentralized network control, improved spectral efficiency, and increased flexibility in the granularity of bandwidth that can be provisioned. To eliminate the multiple access interference (MAI), spectral-phase coding was proposed to use the orthogonality of bipolar codes by programming the phase to 0 and 180 degrees. Since the phase was a very difficult issue to preserve in fiber, the technique of spectral amplitude coding (SAC) with unipolar version is proposed [5]. In spectral amplitude-coding system, the inherent phase-induced intensity noise (PIIN) results in significant performance degradation. To suppress it, a code with lower constant inphase cross-correlation has been used [6]. In OCDMA system, PIIN is strongly related to MAI

due to the overlapping of spectra from different users [7]. It is important in OCDMA to select suitable codes for all the online users, such as the maximum number of the users that can be supported and the BER, depends on the codes selected. Usually optical orthogonal codes (OOC), prime codes, MFH codes, and Hadamard codes [6–8] perform well due to their low correlation value and relatively large code space. 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 codes). In this paper, we focus on the design of RD codes used in variable weight system among those codes. This code is constructed using code segment and data segment. One of the important properties of this code is that the cross correlation at data segment is always zero.

2 Construction of the RD code’s matrixes

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 inphase cross- correlation

of two different sequences $X=(x_1, x_2, \dots, x_N)$ and $Y=(y_1, y_2, \dots, y_N)$. When $\lambda=0$, it is considered that the code possesses zero cross correlation. The design of this new code can be performed by dividing the code sequence into two sub-matrixes which are code sub-matrix and data sub-matrix [9]. The advantages of dividing the RD codes into two parts became easier for hardware implementation using direct detection rather than using different types of detection techniques. Another major advantage of our new codes, including both MQC and MFH, lies in the first property, i. e., elements in each sequence can be divided into groups and each group contains only one “1”. This property makes it much easier to realize the address reconfiguration in a grating-based spectral amplitude-coding optical CDMA transmitter. We can use a group of gratings to reflect all the desired spectral components; and

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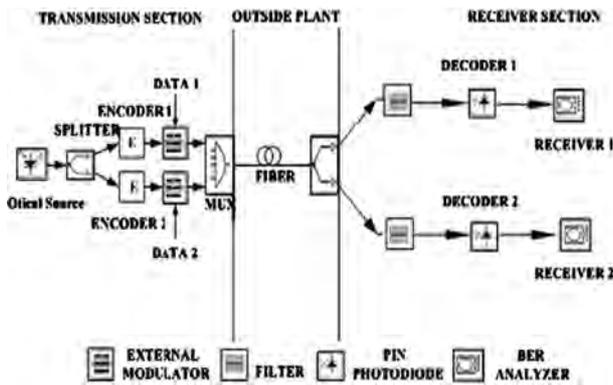


Fig. 2: Simulation setup of the proposed transceiver scheme

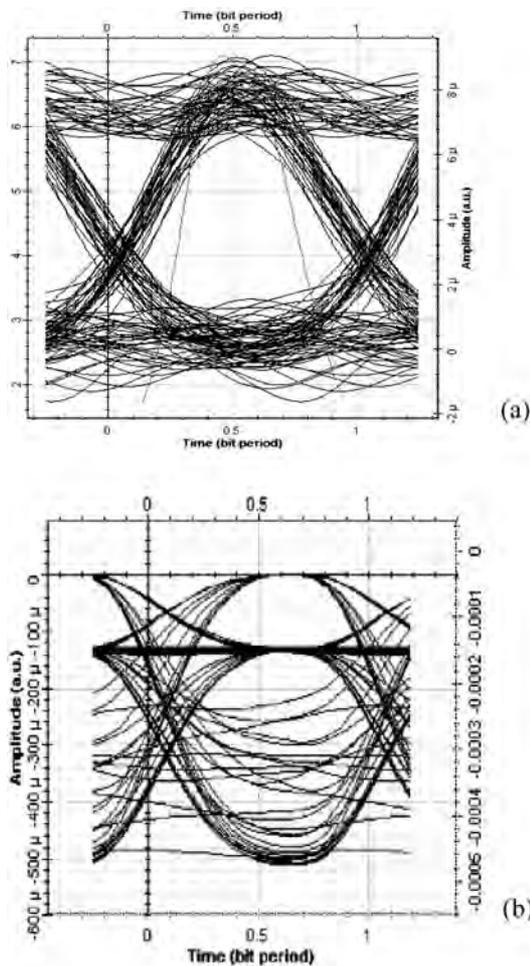


Fig. 3: Eye diagram of (a) one of the RD channels, (b) one of the MQC channels, at 10 G bit/s

where e is the electron charge, K_B is the Boltzman constant, $P_{sr} = -10$ dBm is the optical received power, $B = 311$ MHz is the receiver's noise-equivalent electrical bandwidth, $\eta = 0.6$ is the photodetector quantum efficiency, $\Delta V = 3.75$ THz is the linewidth of the broadband source, $\lambda = 1550$ nm is the operating wavelength, $T_n = 300$ K is the receiver temperature, $R_L = 1030 \Omega$ is the receiver load resistance and W , N , and K , are the code weight, code length, and total number of active users, respectively, as being the parameters of RD code itself. The bit-error-rate (BER) or probability of error, P_e , is

estimated using Gaussian approximation [9, 11, 14, 15] as $P_e = 1/2 \operatorname{erfc}(\sqrt{SNR}/8)$.

Fig. 4 shows the relation between the number of users and the BER, for RD, MFH, MQC and Hadamard codes, for different values of K (number of users). It is shown that the performance of the RD code is better compared with the others even though the weight is far less than other codes, which were 7 in this case. The maximum acceptable BER of 10^{-9} was achieved by the RD code with 20 active users. This is good considering the small value of weight used. 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. However, a few code specific parameters were chosen based on the published results for these practical codes [9, 11, 13, 14]. The calculated BER for RD was achieved for $W=5$ while for MFH, MQC and Hadamard codes were for $W=10$, $W=12$, and $W=64$, respectively.

4.2 Performance analysis of variable weight RD code

Using the same transceiver system with the same parameters listed in Fig. 3, a variable weight users C_x was applied to the system to support 9 users with three different weights $W=3, 4$, and 5 . One of the most important differences between single weight system and variable weight system is that PIIN leads to changes, since each user is different from the other user by the number of weights, and this can be explained in more detail as follows. When all active users are transmitting bit "1" the code sequence for single weight system can be expressed as $\sum_{k=1}^K C_k = KW/N$; however, for a variable weight system, the total number of active users at a given time is the summation of different weight that coexists in a single system, denoted by $K_x = \sum_{j=1}^w K_j$, where j is the number of different weights used in single system, and w is the total number of different weights. Therefore C_x can be approximated as $\sum_{k=1}^{K_x} C_k = (1/N_x) \sum_{j=1}^w K_j W_j$. This leads to the variance of PIIN as

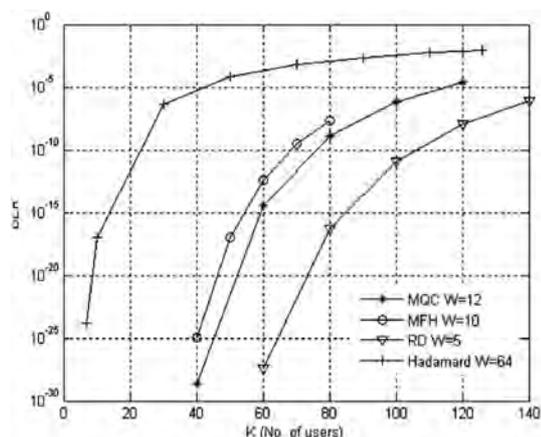


Fig. 4: BER against the number of active users for various codes employing SAC technique

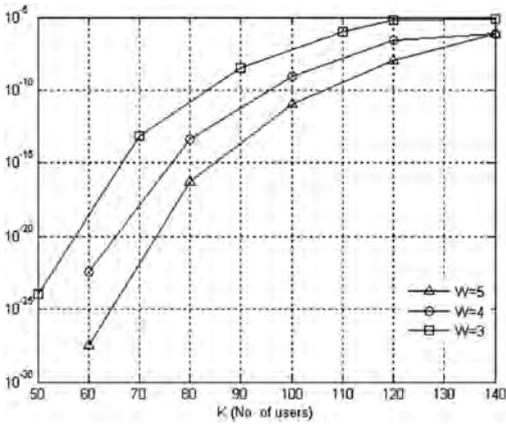


Fig. 5: BER performance for variable weight RD code system

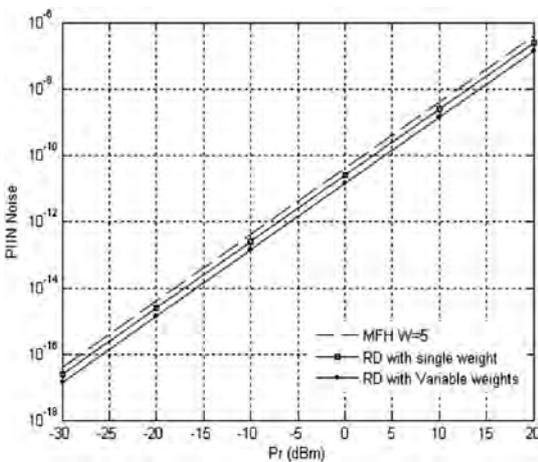


Fig. 6: PIIN versus P_r for variable weight RD code, single weight RD code and MFH code for $K=9$

$$I^2 = \frac{P_{sr}^2 \cdot \sum_{j=1}^w K_j W_j (K_j - 1 + W_j) \mathfrak{R}^2}{\Delta V \cdot N^2}$$

The average SNR for users of particular weight of interest, W_j , with the presence of other users of different weight, is given as

$$SNR_x = \frac{\left(\frac{2\mathfrak{R}P_{sr}W_j}{N_x}\right)^2}{\frac{2eBW_jP_{sr}\mathfrak{R}}{N_x} + \frac{B\mathfrak{R}^2P_{sr}\sum_{j=1}^w W_jK_j}{2N_x^2\Delta V} (K_j - 1 + W_j) + \frac{4K_B T_n B}{R_L}}$$

Figure 5 depicts the BER of large ($W=5$), medium ($W=4$) and small ($W=3$) weight RD codes while varying the large weight users, K from 0 to 140. Three different weights used in the simulation are 3, 4, and 5. It can be seen that the BER for codes of all weights worsen as the total number of simultaneous user's increases, since more users in a system increase the noise level and further degrade the system performance. BER for $W=5$ has the smallest error probability in all the other cases ($W=4$ and $W=3$) due to larger weight that contributes to higher received signal. For example at $K=90$ the BER = $5 \cdot 10^{-8}$, $8 \cdot 10^{-12}$ and $2 \cdot 10^{-14}$ for $W=3, 4$ and 5 respectively. At this point in time the number of large weight users had dominated the networks, thus contributing to higher probability of error.

Next, we investigated the PIIN noise for various received power using the same system parameters used in the previous section. In OCDMA systems, phase induced intensity noise (PIIN) is related to multiple access interference (MAI) due to the overlapping of spectra from different users. Here, we analyzed the relations between PIIN noise and received power. The system was simulated using variable weight code ($W=3, 4,$ and 5), single weight system $W=5$, and for MFH code with $W=5$. From Fig. 6, it can be observed that the system performance was improved using RD code with variable weight rather than for RD code with single weight system and MFH code. This result can be explained as follows. The system performance improved for a long code, since generally as the code length increases, the distributed chips become less frequent; thus, when a desired user sends a "0" its signal is statistically less disturbed. Therefore, for a given dispersion and the fiber length, longer code improves the system performance. From this figure, one can see that the PIIN noise can be effectively suppressed by using variable weight RD code family.

4 Conclusions

In this paper, a variable weight RD code family is performed for spectral amplitude coding OCDMA system with zero cross-correlation at data segments. It is shown to achieve similar BER of 10^{-10} ; RD code is capable of supporting 20 more users than MQC with smaller weight (7 weights less than MQC). The ability of RD code to support services in multimedia applications has been presented, where three different code weights can be obtained with a proper choice of supportable users. Codes with large weight always have smaller BER even when the code length is long. The PIIN is also an important system limitation which must be reduced. Thus in an access optical network, when the variable weight is used, PIIN is suppressed significantly and the overall network performance can be improved. This proposed technique can be an excellent candidate for use in next generation OCDMA networks applications.

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