Enhanced Double Weight Code Implementation in Multi-Rate Transmission

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Summary
This paper presents new code ability in supporting multiple transmission rates in point to point (P2P) spectral amplitude coding- optical code division multiple access (SAC-OCDMA) links. Enhanced double weight (EDW) code is derived from double weight (DW) code. Enhanced double weight (EDW) code possess ideal cross-correlation properties and weight can be any odd number which is grater than one. It has been observed that theoretical analysis and simulation for EDW code is much better performance compared to Hadamard and Modified Frequency Hopping (MFH) codes. The ability EDW code to support simultaneous transmissions at different bit rates is shown through simulated results of the bit error rate (BER) and the eye patterns.

Key words:
SAC-OCDMA, Double Weight (DW) code, Enhanced Double Weight (EDW) code.

1. Introduction

Many codes have been proposed for optical CDMA system [1], [2]. However only a few of them [3], [4] have been shown to actually support multi-rate transmissions. The multi-rate transmission is on of the main advantages of OCDMA systems which provide asynchronous transmissions as opposed to the synchronous time division multiplexing (TDM) system. However it is also not very clear if any of the codes has been tested on the actual fiber or even on the software-simulated environments. As such the transmission in fiber optics has not really been proven. This is a major lacking considering the importance of the effects of fiber material interaction with the light wave on the transmission performance, especially of the chromatic dispersion effect. Many of the reports have neglected the effect of dispersion whereas in systems such as optical CDMA where the combined spectral width is broad, dispersion plays a very important factor in limiting the system performance.

In this paper the simulated results and theoretical analysis are presented to show the ability of the newly proposed EDW codes to support multiple bit rate transmissions. The results are compared against that of the Hadamard and Modified Frequency Hopping (MFH) codes [5]. It is found that EDW codes can support both 2.5 Gbps, and 10 Gbps transmission rates simultaneously with a better performance compare to other codes. While for theoretical effect, EDW code have much lower BER than the one uses Hadamard and MFH codes.

2. Review of EDW Code

EDW code [6] is an enhanced version of DW code as reported in [7]. The EDW code weight can be any odd number that is greater than one. The code weight has a direct effect on the performance of an OCDMA system; generally, increased weight results in better SNR [5], [8]. This is because by increasing the code weight necessarily increases the signal power of the user, hence increasing the signal-to-noise ratio.

EDW code can be represented by using a $K \times N$ matrix. In EDW codes structures, the matrix K rows and N columns represent the number of users and the minimum code length respectively.

The basic matrix H_1 for EDW codes consists of a $K_1 \times N_1$ matrix whose size depends on the value of code weight, W as given below

Manuscript received December 5, 2007
Manuscript revised December 20, 2007

$$K_1 = W \tag{1}$$

$$N_1 = \sum_{j=1}^{w} j \tag{2}$$

From the basic matrix, a larger value of K can be achieved by using a mapping technique as shown in Equation 3.

$$H_i = \begin{bmatrix} 0 & H_1 \\ H_1 & 0 \end{bmatrix} \tag{3}$$

where i =2,3,….is the mapping sequence of the codes.

The mapping sequence, i (together with W) determine the value of user, K and code length, N as given by equations 4 and 5.

$$K = i \times W \tag{4}$$

$$N = i \times \sum_{j=1}^{w} j \tag{5}$$

The resulting matrix will consist of a chip-combination sequence of 1,2,1,2… (alternating 1 and 2) for the columns (counting from leftmost). A chip-combination is defined as the summation of the spectral chips (1's and 0's) for all users (or rows) in the same column.

In this paper, the EDW code with the weight of three is used as an example. The basic EDW code denoted by (6, 3, 1) is shown below

$$H_1 = \left|\begin{array}{cc|cc|cc} 0 & 0 & 1 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 & 0 & 0 \end{array}\right| \tag{6}$$

An EDW code with weight of 3 denoted by (N, 3, 1) for any given code length N, can be related to the number of user K through

$$N = 2K + \frac{4}{3}\left[\sin(\frac{K\pi}{3})\right]^2 \left[\frac{8}{3}\left[\sin(\frac{(K+1)\pi}{3})\right]^2 + \frac{4}{3}\left[\sin(\frac{(K+2)\pi}{3})\right]^2\right] \tag{7}$$

3. Performance Analysis

The performance of EDW, MFH and Hadamard codes was simulated by using commercial simulation software, OptiSystem Version 4.0. A simple schematic block diagram consisting of 12 users is illustrated in Figure 1. The tests were carried out at the rate of 2.5 and 10 Gbps for all the codes. Channels 1 to 6 are running at 10 Gbps, while Channels 7 to 12 are at 2.5 Gbps. The complementary subtraction technique, which is also known as balanced detection technique [9], [10] was used.

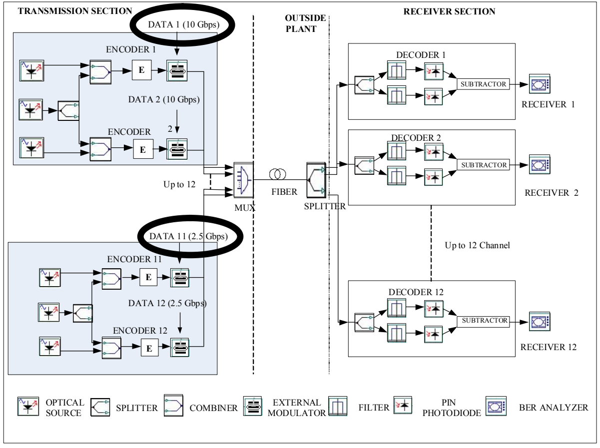

Fig. 1 The system architecture of the OCDMA network

The fiber length is varied from 10 km to 30 km. EDFA was used (Gain = 15 dB and Noise figure = 4 dB). At the receiver side, the incoming signal is split into two parts, one to the decoder that has an identical filter structure with the encoder and the other to the decoder that has the complementary filter structure. A subtractor was used to subtract the overlapping data from the wanted one. The performance of the system is characterized by referring to the bit error rate and the eye patterns.

The fiber used has the parameters' values taken from data which are based on the G.652 Non Dispersion Shifted Fiber (NDSF) standard. This includes the attenuation, group delay, group velocity dispersion, dispersion slope and effective index of refraction, which are all wavelength dependent. The nonlinear effects such as Four Wave Mixing and Self Phase Modulation are also activated. At 1550 nm wavelength, the attenuation coefficient is 0.25 dB/km, chromatic dispersion coefficient is 18 ps/nm-km. The transmit power used is 0 dBm out of the broadband source. The noises generated at the receivers are set to be random and totally uncorrelated. The dark current value is 5 nA and the thermal noise coefficient is $1.8\text{x}10^{-23}$ W/Hz for each of the photo-detectors.

The eye pattern diagrams for Channel 1 (10 Gbps) and Channel 12 (2.5 Gbps) are shown in Figure 2(a) and 2(b) respectively for EDW code. Figures 3(a) and 3(b) are for Hadamard and MFH codes respectively taken after only 10km of fiber optics length at 10 Gbps rate.

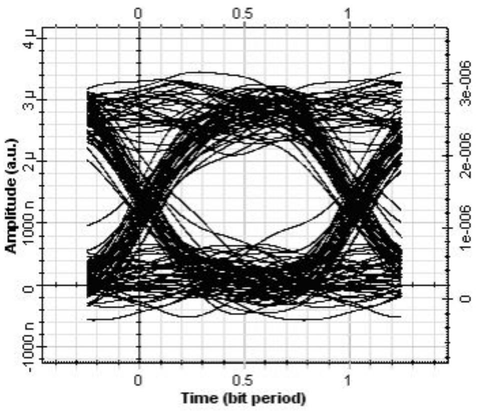

Fig. 2(a) Eye diagram of the EDW channel 1 at 10Gbps with BER of 9.81×10^{-9} after 10km transmission.

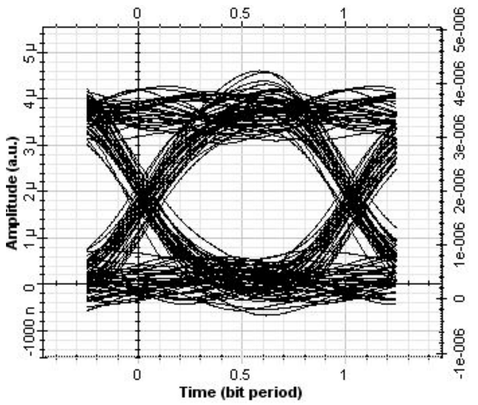

Fig. 2(b) Eye diagram of the EDW channel 12 at 2.5Gbps with BER of 8.53×10^{-11} after 30km transmission.

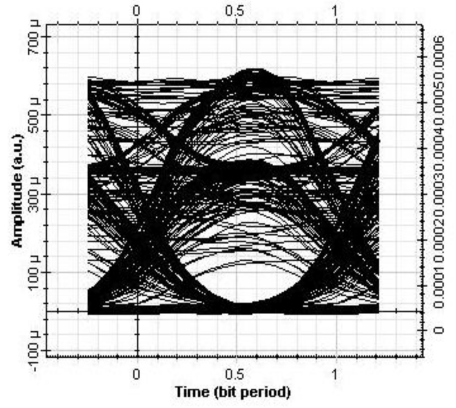

Fig. 3(a) Eye diagram of one of the Hadamard channels at 10Gbps with BER of 3.50×10^{-4} after 10km transmission.

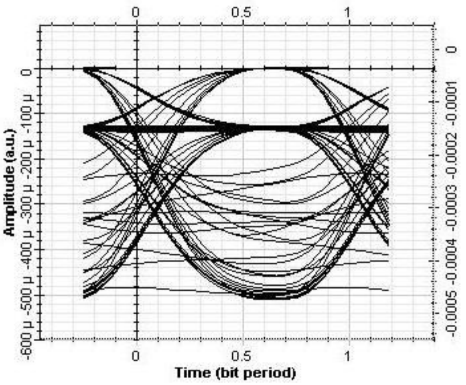

Fig. 3(b) Eye diagram of one of the MFH channels at 10Gbps with BER 5.7×10^{-3} after 10km transmission

The eye patterns shown in Figure 2 above clearly depict that the EDW code system gave a significantly better performance than the system running on Hadamard codes Figure 3(a) and on MFH code Figure 3(b). Figure 3 also clearly shows the cross-talks experienced by Hadamard and MFH codes [11]. The cross-talk is not present in the eye pattern of EDW code.

Another advantage of EDW code is that the spectrum overlapping occurs only for one chip at all times regardless of the number of users. In other codes, the overlapping is maintained at only a single chip for combination of two users only. If more users are operating at the same times then the overlapping chips will increase, resulting in crosstalk, as shown in figures 3(a) and 3(b)

The signal to noise ratio (SNR) expression in Equation (8) as adopted in many previous reports [3] clearly predicts that the SNR increases, thus the BER reduces with spectral width.

$$SNR = \frac{2\left(\frac{W}{\lambda} - 1\right)\Delta v}{BK\left[\frac{K}{2} + \frac{W}{\lambda} - 2\right]} \tag{8}$$

where Δv is the spectral width, W is the code weight, K is the number of simultaneous users, B is the noise equivalent electrical bandwidth of the receiver and λ is the cross correlation between sequences.

Figure 4 shows the signal-to-noise ratio (SNR) versus with number of users when different codes are used. In this figure we have been used the following parameters: Δv =0.8nm, B=311MHz (for bit rate 622 Mbps) at the operation wavelength of 1550 nm. It clearly shows that the EDW code can support more users compared with MFH and Hadamard codes.

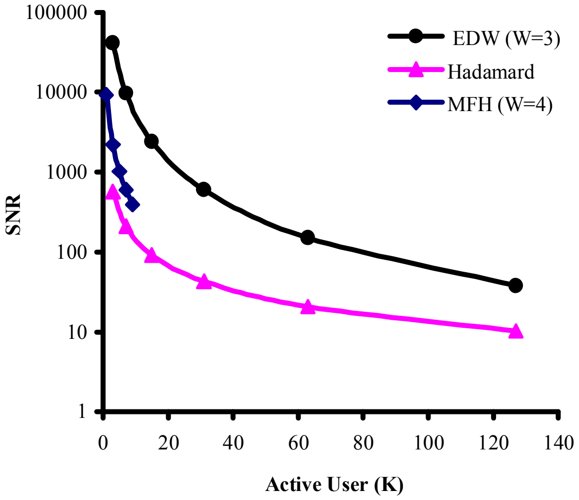

Fig. 4 SNR versus number of users for EDW, MFH and Hadamard codes using $\Delta\lambda = 0.8$ nm, B = 311 MHz at the operating wavelength of 1550nm.

Figure 5 shows the bit-error rate (BER) versus the number of users when different DW code families are used. It clearly shows that MDW [7] code can support more users compared with EDW and DW codes. Note also that the calculated BER MDW is achieved for W=4 while for EDW, W=3 only. EDW code should perform better if a larger code weight were used.

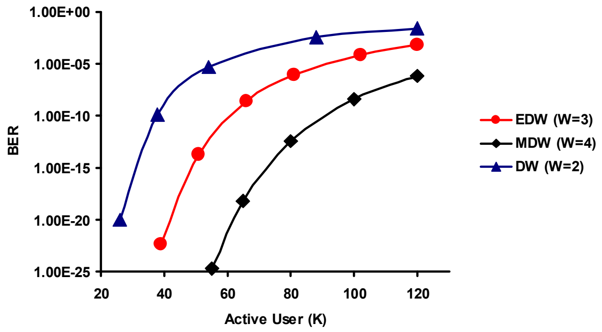

Fig. 5 BER versus number of users for EDW, MDW and DW codes using $\Delta\lambda = 0.8$ nm, B = 311 MHz at the operating wavelength of 1550nm.

4. Conclusion

The basic SAC-OCDMA architecture naturally possesses a number of desirable features. The advantages of CDMA include the flexibility in the allocation of channels, and the ability to operate asynchronously. The all-optical multiplexing results in a protocol agnostic system in which channels can be carried at any combination of data rates and formats in an independent, unsynchronized fashion. This paper presents the transmission of carriers encoded with the EDW code at two different bit rates, 2.5 Gbps and 10 Gbps. The results of a point-to-point (P2P) link carrying 12 differently encoded carriers clearly show the ability of the system to support muli-rate transmissions. The EDW code also has been proven to provide a better performance compared to the systems encoded with MFH and Hadamard codes. This is due to the ability of EDW code sequences to maintain a minimum overlapping spectrum (only one chip) at all times regardless ot the number of users.

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