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SAC-based OCDMA codes: A comparison

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Abstract: Optical code division multiple access (OCDMA) is one of the promising optical access technologies due to its worth-mentioning features, such as asynchronous access, and high security. In this paper, the author performed an analytical-based comparison between three commonly used spectrum amplitude coding SAC-based OCDMA codes, namely: Modified Frequency Hopping (MFH), Hadamard, and Enhanced Double Weight (EDW). The comparison was made based on bit-error-rate (BER) observation in each case. Matlab was used to conduct this comparison. The results confirm that EDW is the best choice due to its fixed weigh. The only dilemma when adopting EDW code is how to select the proper weight.

Keywords: optical CDMA, MFH code, Hadamard code, EDW code, multiple access interference MAI.

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1. INTRODUCTION

After the successful implementation of code division multiple access (CDMA) technology in the wireless communications, it rapidly became a potential solution that might be adopted for service in the optical communications field along with the frequency division multiple access (FDMA) and time division multiple access (TDMA) technologies [1] [2]. The reason that makes CDMA very distinguishable is the possibility of accessing the transmission medium by large number of users at the same time using the same bandwidth. Unlike FDMA and TDMA techniques in which a single carrier is temporarily assigned for each user, CDMA uses a unique code as an alternative. This code is modulated by the data to be transmitted, which theoretically makes CDMA is capable of accommodating an infinite number of users, but nevertheless noise plays the major role in determining the extent to which CDMA can accommodate users. Also, CDMA is more secure as each modulated code can only be recognized by an intended receiver. More advantages of CDMA over FDMA and TDMA can be found in [1] [2]. Despite these advantages, CDMA suffers from the problem of multiple access interference (MAI) due to the shared transmission medium. In fact, MAI can possibly be reduced by using detection methods that are based on subtraction techniques, such as complementary, AND, Modified-AND, NAND, and XOR subtraction techniques, however, these methods are somewhat complicated and not cost effective due to the need to use more than one filter in each receiver [3] [4] [5] [6] [7]. Another innovative approach to reducing MAI is to design a code with small cross correlation. In this context, Anas et all in [8] implemented a new service differentiation technique in the optical domain using SAC variant of OCDMA. The newly developed code, named KS (Khazani–Syed) is compared mathematically with other codes which use similar techniques. The results showed that KS offers a significantly improvement in the performance by accommodating additional 30 users with shorter code length and smaller code weight. Fadhil et all in [9] studied the performance of random diagonal (RD) code for SAC-OCDMA system using a newly proposed spectral direct detection technique. One of the important properties of this code is that the cross correlation at data segment is always zero. The results showed that the proposed new spectral direct detection technique utilizing RD code considerably improves the performance compared with the conventional SAC complementary subtraction technique. A class of signature sequences called optical orthogonal codes (OOCs) that provide the auto- and cross-correlation properties required for fiber-optic code-division multiple-access (FO-CDMA) is experimented with different interference patterns to determine the strongest and the weakest performance [10]. Smith et all in [11] proposed a simple and interference-limited performance pulse-position modulation (PPM) decoding structure. The performance of the proposed structure is found to be superior to that of the original system when the number of simultaneous users is of the order of the PPM word length or larger. In particular, for a PPM word length of two, an increase in spectral efficiency of up to 100% is possible with no change in the signaling rate, data rate, or bit-error rate (BER). Wei, Z. in [12] constructed two new codes with ideal in-phase cross-correlation in algebraic ways. Both of the newly proposed codes are obtained by modifying former codes with ideal cross-correlation. The results showed a significant improvement in the performance of the SAC-based systems when adopting the new code constructions where multi user interference is reduced. Geetha and Manoharan in [13] discussed an MAI cancellation technique for OCDMA systems by incorporating M-ary-FSK Modulation and by employing double padded modified prime code as a signature sequence. As compare with the existing pulse position modulation (PPM)-OCDMA system, the FSK-based

OCDMA system could achieve a better performance as it provided lower BER. Abdellah Bensaad et all in [14] introduced a new method for constructing zero cross-correlation (ZCC) codes. The newly proposed method offers a good flexibility in the choice between the number of users, the weight and the code length without any constraint by using transformation and mapping technique respectively. as compared with to other existing codes, the length of the proposed ZCC code was quite small with cross-correlation equals to zero, which can definitely to a reduced MAI. Feng et all in [15] proposed an optical zero correlation zone code that led to reduce the effect of MAI. The proposed code is set in visible light communication quasi-synchronous optical code division multiple access system while taking into account the effects of phase-induced intensity noise, shot noise, and thermal noise. Chauhan et all in [16] presented an algorithm to design optical orthogonal codes (OOCs) and determines the auto-correlation and cross-correlation constrains of codes. The OCCs codes were grouped using a low complexity bipartite method. The bipartite scheme for grouping finds all possible and desirable auto-correlation and cross-correlation to achieve a low MAI. It also reduced the time of computation, the memory requirement, and computational complexity. The process of transmission and reception based on OCDMA technology is schematically illustrated in Figure 1.

ones in the code sequence), the cross correlation, respectively. The cross correlation is defined as the sum of ones resulted from multiplication of any two code sequences (the number of spectral overlapping between the two sequences). It is given as [17]

$$\lambda_c = \sum_{i=1}^{N} x_i y_i \, , x = (x_1, x_2, x_3, \ldots, x_N),$$
$$y = (y_1, y_2, y_3, \ldots, y_N) \quad (1)$$

2.1 MFH Code

Modified frequency hopping code is an upgraded version of frequency hopping code [18]. It is characterized as a low cross correlation code where $\lambda_c = 1$. MFH is constructed based on prime power, thus it can support a number of users k = q^2. The length and weight of MFH are given as $N = q^2 + q$, and $W = q + 1$, $W = q+1$, respectively. For MFH code, the form (N, W, λ_c) can be written equivalently as (q^2+q, $q+1$, 1). For MFH code, the form (N, W, λ_c) can be written equivalently as (q^2+q, $q+1$, 1).

2.2 Hadamard Code

A Hadamard code can be represented by ZxZ orthogonal matrix that filled up with (-1, 1) binary entries. Any individual row within the Hadamard orthogonal matrix represents a Z-element. The ZxZ Hadamard matrix is customarily abbreviated as H_M, where $M = \log_2 Z$.

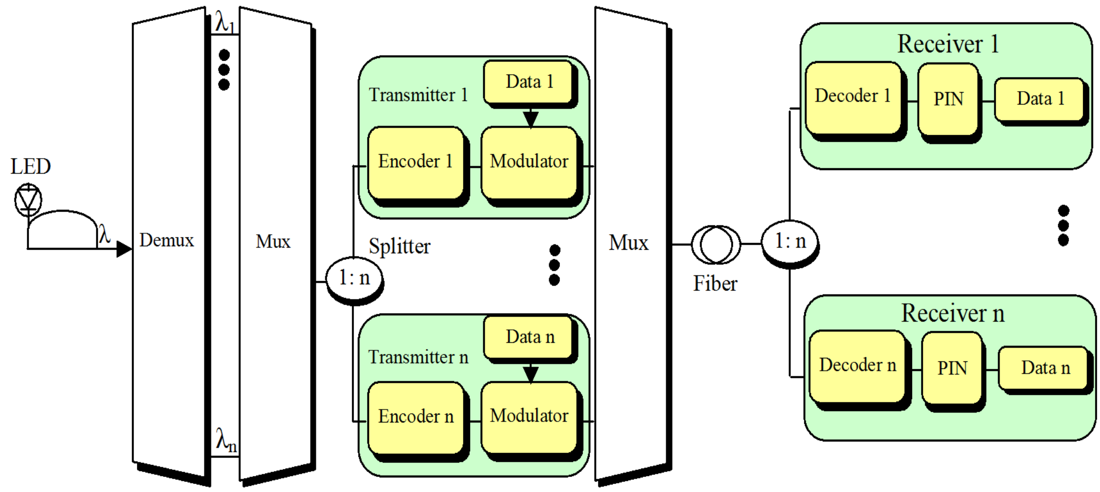

Figure 1. An OCDMA-based transmission system

In this paper, the author performed a comparison between three commonly used SAC-based OCDMA codes, (MFH, Hadamard, and EDW codes). The aforementioned SAC-based codes were chosen due to their different characteristics. For example, MHF code has variable weight and fixed cross correlation, Hadamard code has variable weight and variable cross correlation, whereas EDW has fixed weight and fixed cross correlation. The comparison was made using analytical approach based on BER observation in each case. Matlab was used to conduct this comparison.

2. MFH, Hadamard, and EDW Codes Construction

Mathematically, a code can be expressed as (N, W, λ), where N, W, and λ represent its length (the number of ones and zeros in the code sequence), weight (the number of

A ZxZ Hadamard matrix is simply constructed by using a repetitive pattern of an intermediate matrix called the core matrix $H_{M=1}$. The core matrix $H_{M=1}$ is given as [19]

$$H_{M=1} = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \quad (2)$$

For example, for M = 2, a 4 x 4 Hadamard orthogonal matrix is constructed as

$$H_{M=2} = \begin{bmatrix} H_{M=1} & H_{M=1} \\ H_{M=1} & -H_{M=1} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{bmatrix} \quad (3)$$

It is more convenient to replace the entries of negative ones with zeros, which yields

$$H_{M=2} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 \\ 1 & 1 & 0 & 0 \\ 1 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

Practically, Hadamard codes are valid only for M ≥ 2, and can support a number of users $k = 2^{M-1}$, with variable weight and cross correlation related to the matrix sequence M as $W = 2^{M-1}$, $\lambda_c = 2^{M-2}$, respectively. For Hadamard code, the form (N, W, λ_c) can be written equivalently as (2^M, 2^{M-1} , 2^{M-2}).

2.3 EDW Code

EDW code is an enhanced version of the double weight DW code. It is characterized as a low cross correlation code, where $\lambda_c = 1$. Unlike DW code, where the code weight is always two, the weight in EDW can be any odd number which is greater than one. EDW code can be represented by K x N matrix, where K and N represent the number of users and code length, respectively. A K x N EDW matrix can be simply constructed using a repetitive pattern of an intermediate matrix called the basic matrix. This process is also referred to as mapping technique [20]. An example of basic matrix can be represented by the following 3 x 6 matrix. Note that a weight of 3 is chosen in this example.

$$H_o = \begin{bmatrix} 0 & 0 & 1 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 & 0 & 0 \end{bmatrix} \quad (5)$$

For example, a 6 x 12 EDW matrix can be constructed as

$$H_1 = \begin{bmatrix} 0 & H_o \\ H_o & 0 \end{bmatrix} = \begin{bmatrix} 0&0&0&0&0&0&0&0&1&1&0&1 \\ 0&0&0&0&0&0&0&1&0&0&1&1 \\ 0&0&0&0&0&0&1&1&0&1&0&0 \\ 0&0&1&1&0&1&0&0&0&0&0&0 \\ 0&1&0&0&1&1&0&0&0&0&0&0 \\ 1&1&0&1&0&0&0&0&0&0&0&0 \end{bmatrix} \quad (6)$$

EDW code can support a number of users $K = 2^n$, where n represents the number of rows in the basic matrix H_o. In the case of EDW code with weight of 3, the form (N, W, λ_c) can be written equivalently as (N, 3, 1), where the code length N is related to the number of users K as

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

3. CODES COMPARISON

In this part, MFH, Hadamard, and EDW codes were compared using its characteristics. The comparison was in particularly made by observing the BER in each case. In order to facilitate the comparison process, the characteristics of the above mentioned CDMA codes were listed in Table 1.

Table 1. MFH, Hadamard, and EDW codes characteristics

Code	Number of users	Length	Weight	Cross correlation
MFH	K = q2	N = q2 + q	W = q + 1	λc = 1
Hadamard (M ≥ 2)	K = 2M-1	N = 2M	W = 2M-1	λc = 2M-2
EDW	K = 2n, (n = number of rows in the basic matrix Ho)	N according to (7)	odd number > 1	λc = 1

For the OCDMA codes, the signal to noise ratio (SNR) is approximately expressed as [21]:

$$SNR = \frac{2\left(\frac{W}{\lambda_c} - 1\right)\Delta v}{BK\left(\frac{K}{2} + \frac{W}{2} - 2\right)} \quad (8)$$

where W, λ_c , and K are the weight, cross correlation, and number of users, respectively. B is the receiver noise bandwidth; Δν is the optical bandwidth which can be calculated as $\Delta v = \left(c/\lambda\right)^2 \Delta\lambda$, where c, λ, and Δλ are the speed of light, wavelength, and spectral width, respectively. Using Gaussian approximation, BER can be expressed as [22]:

$$BER = \frac{1}{2} erfc\left(\sqrt{\frac{SNR}{8}}\right) \quad (9)$$

Figure 2 show BER versus number of users at MFH, Hadamard, and EDW codes. From the graph, one can decide that MFH is the best choice due to the lowest BER it shows; nevertheless this decision may not be quite accurate. This is because the weight in MFH code is not fixed as in the case with EDW. In fact, the weight in MHF code increases as the number of subscribers increases.

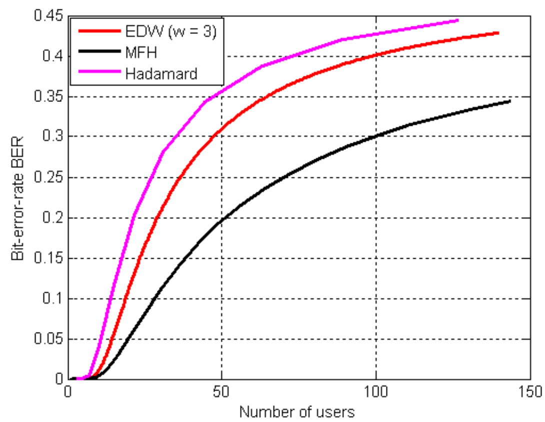

Figure 2. BER vs. number of users at MHF, Hadamard, and EDW codes

In order to verify the validity of these conclusions, we increased the weight of EDW code to 13, which is the same weight of MFH code when the number of subscribers reaches 144.

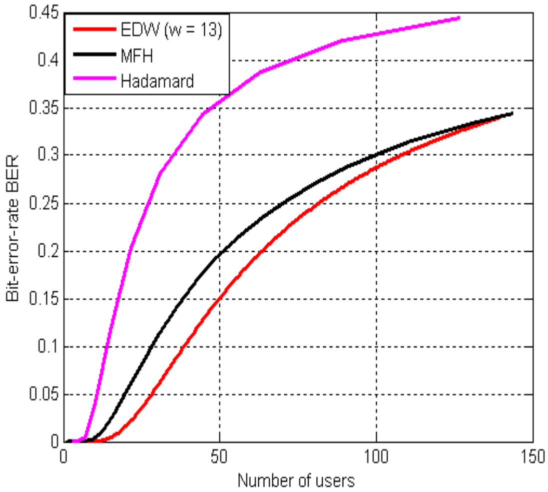

Figure 3. BER vs. number of users at MHF, Hadamard, and EDW codes, (w = 13 for EDW code)

Figure 3 show BER versus number of users at MFH, Hadamard, and EDW (W = 13) codes. It can be obviously observed that EDW code shows the best performance until the point where the number of subscribers reaches 144 (I.e., the point in which both MFH and EDW codes has an identical weight). Based on this observation, one can decide that the code with longer weight is the best choice. Nevertheless, once again, this decision may not be quite accurate. In other word, one can see from the graph that Hadamard code shows the worst performance although it has an increasing weight as in the case with MFH code. Going deeply into the codes characteristics, one can attribute this to the increasing cross correlation that Hadamard has as well. Figure 4 clarifies this fact.

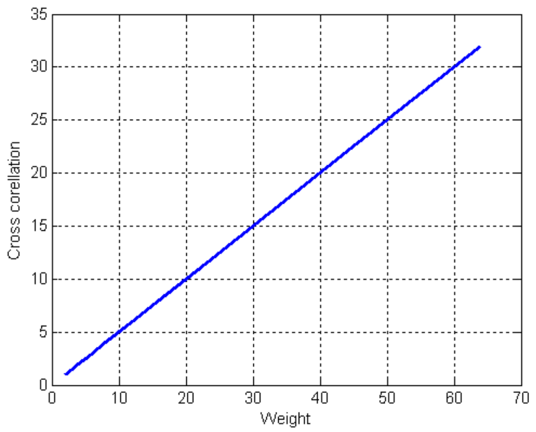

Figure 4. Cross correlation vs. weight for Hadamard code

5. CONCLUSIONS

Based on the results obtained, the code with longer weight and lower cross correlation shows a better performance. This is attributed to the increased power within the code sequence, which definitely leads to a better SNR. However, adopting a code with too long weight would necessitate the use of very narrow-bandwidth filters, which complicates the receiver circuitry and thus increase the cost. Based on these inferences, we conclude that EDW is the best choice due to its fixed weigh. In other word, the only dilemma when adopting EDW code is how to select the proper weight.

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