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ORIGINAL ARTICLES

Investigation the performance of unipolar SAC-OCDMA codes

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ABSTRACT

In this paper, we investigate the performance of unipolar Spectral Amplitude Coding Optical Code Division Multiple Access (SAC-OCDMA) codes. A performance comparison made between various unipolar SAC-OCDMA codes such as Random Diagonal (RD), Modified Double Weight (MDW), and Modified Quadratic Congruence (MQC) codes. Mathematical expressions have been used to analyze the bit-error rate (BER) value for each code depending on the number of simultaneous users (K), Effective Power (Psr), and Electrical Bandwidth (EB). The mathematical analysis shows that the system performance of the RD code is better than the MDW and MQC codes at -10 dBm effective power of the light source. In contrast, the MDW code shows a better performance, especially when the effective power of light source is more than -5dBm. Our results indicate that RD code provides a better performance over other SAC-OCDMA codes. In other words, The ability of RD code to support large simultaneous users with low effective power of light source appropriate it to be perfect solution to the SAC-OCDMA networks.

Key words: Spectral Amplitude Coding (SAC); Optical Code Division Multiple Access (OCDMA), Random Diagonal (RD); Modified Double Weight (MDW); Modified Quadratic Congruence (MQC).

Introduction

Ever since the mid-1980s when single-mode fiber-optic media were believed to become the main highways of future telecommunications networks for transporting high-volume high-quality multipurpose information (Abtin Keshavarzian, 2002). The biggest technical challenge for today’s communication network systems is to take more information carrying capacities since the volume of information produced increases rapidly with the substantial growth in data traffic, since the need for higher capacity optical systems increases (Chandigarh Engg, 2009). Optical Code Division Multiple Access (OCDMA) is one technique of the multiple access technique to allow several users to transmit simultaneously over the same optical fiber (Jyotisna Rishi and Dr.R.S.Kaler, 2010). OCDMA is a highly flexible technique to achieve high–speed connectivity with large bandwidth. In the OCDMA networks, multiple users can access the same channel with help of various coding techniques; these codes help maintaining low correlation between users and also help maintain low interference for each user. OCDMA systems suffered from multi access interferance (MAI) when the system involved large number of users. However, Spectral Amplitude Coding (SAC) scheme has been introduced to eliminate the Multiple Access Interference (MAI) effect and preserve the orthogonality between users in the OCDMA systems (Anuar, M.S., 2009). Recently several codes' families are used in SAC–OCDMA networks, such as Random Diagonal (RD) code, Modified Quadratic Congruence (MQC) codes, Modified Double Weight (MDW), Zero Cross Correlation code (ZCC), and Optical Orthogonal Code (OOC) and others (Abtin Keshavarzian, 2002; Anuar, M.S., 2009; Wei, Z., 2001; Syed Alwee Aljunid, 2004; Hilal Fadhil, 2010). OOC code introduced in the form of (N, W, λa, λc). OOC code is a set of (0,1) sequences of length N and weight W (the number of ones in every codeword), λ_a is auto-correlation, and λ_c is cross-correlation. The OOC codes have been designed following requirement for $\lambda_a=1\leq\lambda_c$. There are several mathematical or geometrical ways to design such codes. However, the main restriction is that they are very sparse codes and they need to very long code sequences in order to accommodate even a moderate number of subscribers. The number of sequences in a family of OOC codes is also very limited. It has been calculated that for 6000 chip code period with eight 1’s in the code there are only 100 OOC sequences (Hasoon, F.N., 2006). The SAC–OCDMA networks assign one unique spectral amplitude codeword for each network user to code the amplitude of a light source spectrum. The incoherent source appears as a good candidate for SAC-OCDMA systems as it is inherently. In this paper, we evaluate the performance of SAC-OCDMA codes such as RD, MDW, and MQC codes by using analytical expressions in different values of effective power and electrical bandwidth depending on BER and the number of users. This paper is organized as follows. In Section II, SAC-OCDMA codes construction are explained. Section III, is devoted to numerical system evaluation, and finally, conclusions are given in Section IV.

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SAC-OCDMA codes construction:

A. MQC code construction:

MQC code family introduce in the form of (p^2+p, $p+1$, 1), where p is prime number. MQC code can be constructed using the following steps.

Step 1: First construct a sequence of integer numbers as;

$y_{\alpha,\beta}(k)=\{ [d(k+\alpha)^2 +\beta] \ (\mathrm{mod}\ p),\ k=0,1,....,p-1 \text{ and if } k=p\ [\alpha+b]\ (\mathrm{mod}\ p) \}$.

Where d = { 1,2,3,.....,p-1} and $b,\alpha,\beta=\{0,1,2,....,p-1\}$ Each resulting sequence $y_{\alpha,\beta}(k)$ has (p+1) elements and can be generate p^2 different sequences for each pair of fixed parameters d and b by changing parameters α and β These p^2 different sequences form a code family. Therefore, there are, in total, $p(p-1)$ code families when d and b change.

Step 2: construct a sequence of binary numbers (0, 1) as $s_{\alpha,\beta}(k)$ based on the generated sequence $y_{\alpha,\beta}(k)$ by using the following mapping method :

$s_{\alpha,\beta}(k)=\{ 1 \text{ , if } i=kp+ y_{\alpha,\beta}(k) \text{...and } 0 \text{ , otherwise}\}$.

Where $i=0,1,2,3,.......p^2-1$ and k = $[i / p]$. Here $[i/p]$ denotes the largest integer less than or equal to the value of $[i/p]$ .Table I shows an example of constructing MQC code with the following parameters p=3 and d=1 and b=2 .

Table I: Explain w the procedure for generating (0, 1) sequence $s_{\alpha,\beta}(k)$ based on the number sequence $y_{\alpha,\beta}(k)$.

A	B	$y_{\alpha,\beta}(k)$	$s_{\alpha,\beta}(k)$
0	0	*0110*	*1000-0100-0100-1000*
1	0	*1101*	*0100-0100-1000-0100*
2	1	*2122*	*0010-0100-0010-0010*

The equation of SNR is [5]:

$$\mathrm{SNR}=\frac{(R^2 P_{sr}{}^2/p^2)}{\dfrac{\left(BR^2 P_{sr}{}^2 K\right)\left[\frac{K-1}{P}+P+K\right]}{\left[2\Delta v(P+1)P^2\right]}+\dfrac{eBRP_{sr}(P-1+2K)}{(P^2+P)+4K_b T_n B/R_L}} \tag{1}$$

$$\mathrm{BER}=0.5\ \mathrm{erfc}\left(\sqrt{\mathrm{SNR}/8}\right). \tag{2}$$

B. MDW code construction:

Modified Double Weight (MDW) code has been developed based on Double weight (DW) code family. The DW code can be represented by using a $K\times N$ matrix. Where $K\times N$ matrix represents the number of user (K) and the maximum code length. A basic DW code is given by 2× 3 matrix, as shown below

H1

1	2	1
0	1	1
1	1	0

Notice that *H1* has a chips combination sequence of 1,2,1 for the three columns (i.e 0+1, 1+1, 1+0). A simple mapping technique is used to increase the number of codes as shown below:

H2

0	0	0	0	1	1
0	0	0	1	1	0
0	1	1	0	0	0
1	1	0	0	0	0

$$H2=\begin{vmatrix} 0 & H1 \\ H1 & 0 \end{vmatrix}$$

While the modified version of DW code (MDW code) can be generated for any even number that is greater than two (4, 6, 8 ...). However, as a family of DW code represent, MDW code can be represented by using the same $K \times N$ matrix. In this Paper, the MDW code with the weight of four is used as an example to shows the construction of MDW code.

Hm1

000	011	011
011	000	110
110	110	000

Notice that a similar structure of the basic DW code *H1* is still maintained with a slight modification, whereby, the double weight pairs are maintained in a way to allow only two overlapping chips in every column. Thus, the 1,2,1 chips combination is maintained for every three columns as in the basic DW code. This is important to maintain λ_c=1. The same mapping technique as for DW code is used to increase the number of user in MDW code family (Syed Alwee Aljunid, 2004). The SNR equation of MDW code is given as:

$$\mathrm{SNR}=\frac{2(W/\lambda-1)\Delta v}{BK[K/2+W/\lambda-2]} \tag{3}$$

C. RD code construction:

An (N, W, λ_c) RD code is a family of (0, 1) sequences of length N and weight W, and λ_c is the in-phase cross-correlation which satisfies the following two properties: zero cross-correlation will minimize λ_c and reduce phase induced intensity noise (PIIN); no cross-correlation in data level.

The design of this code can be preformed by dividing the code sequence into two groups, that is, a code level (segment) and data level (segment).

Step 1, data segment**:** let the elements in this group contain only one "1" to keep zero cross-correlation at data level (λ_c = 0), which property is represented by the matrix ($K \times K$), where K represents the number of users, these matrices have binary coefficient and a basic zero cross code (W = 1) is defined as [Y1], for example, three users (k =3), $y(K \times K)$ can be expressed as

$$[Y1]=\begin{vmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{vmatrix}$$

where [Y1] consists of ($K \times K$) identity matrices. Note that 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 for W = 4 as follows:

$$[Y2]=\begin{vmatrix} 1 & 1 & 0 & 1 & 0 \\ 0 & 1 & 1 & 0 & 1 \\ 1 & 0 & 1 & 1 & 0 \end{vmatrix}$$

where [Y2] consists of two parts: a weight matrix part and a basic matrix part; the basic part [B] can be expressed as:

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

and the weight part

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

Notice that in order to increase the number of users simultaneously with the increase of code word length we can just repeat each row on both matrices [M] and [B] (Wei, Z., 2001).

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$$SNR=\frac{(2RP_{sr}W/N)^2}{\frac{2eBWP_{sr}R}{N}+\frac{BRP_{sr}WK}{2N^2\Delta v}(K-1+W)4K_bT_nB/R_L} \quad (4)$$

We can see below in the table II the comparison between the three codes, RD, MDW, and MQC codes according to code length, weight, and cross-correlation.

Table II: Comparison between RD, MDW, and MQC codes.

Code	Code Length (N)	Weight (W)	Cross-correlation(λ_C)
MQC	P^2+P	$P+1$	1
MDW	N=[3n+8/3]sin(nπ/3)^2	W=4	1
RD	$N = K + 2W - 3$	W=4	Variable cross correlation code segment

I. Systems Evaluation:

We investigate the performance of SAC-OCDMA codes using the three codes which are RD, MDW, and MQC codes. We simulate it all for different ways to see which code can support more users and gives better performance, and using the values of *Psr* and *EB* with different numbers of simultaneous users. System parameters have been used based on the previously published papers in (Wei, Z., 2001; Syed Alwee Aljunid, 2004), and table III shows the typical parameters used in the numerical analysis. The numerical analysis is presented as follows:

Table III: typical parameters used in the simulation.

PD quantum efficiency	η= 0.6
Line-width of thermal source	Δv=3.75 THz
Operation wavelength	λ_0 = 1550 nm
Electrical bandwidth	B=80 MHz
Receiver noise temperature	T_r =300 K
Receiver load resistor	R_L = 1030 Ω

Figure (1) shows the relationship between BER and the number of users for SAC codes. It can be observed from this figure that the performance of the RD is better compared with MDW and MQC codes because of several features of the RD code comparing with the other code such as shorter code length, no cross-correlation at data level, data level can be replaced with any type of codes and flexibility in choosing *N*, *K* parameters than other codes. In contrast, MDW code show small system improvement when the number of active users is 100 that is because numerous advantages including the efficient and easy code construction, ideal cross-correlation, and high SNR value.

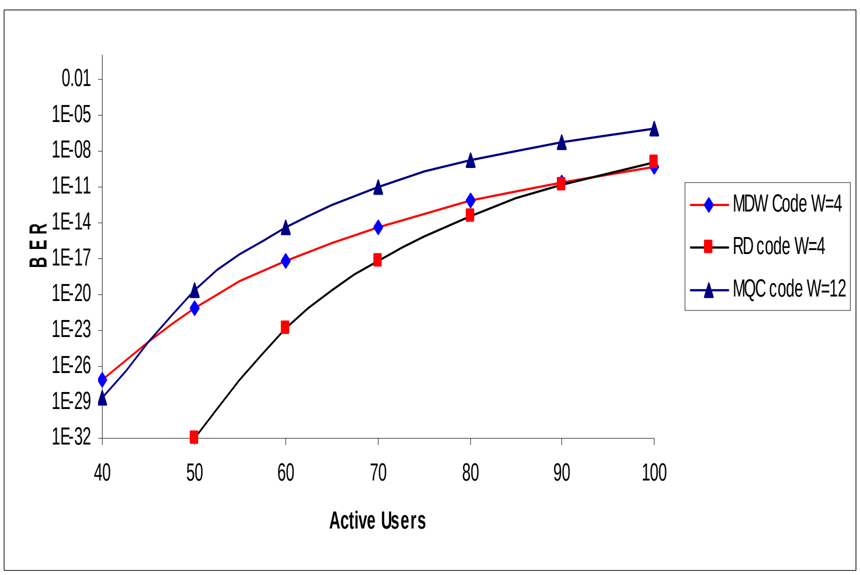

Fig. 1: BER versus number of users for RD, MDW, and MQC codes when the value of *Psr* = -10 dBm and EB = 80 MHz.

Figure (2) illustrate the variance of BER with different Electrical Bandwidth, when the number of stimulants users is 35 and the received power is 0 dBm. We clearly depicts from this figure that the BER will be decrease as increasing the electrical bandwidth. In addition the system with low data rate can support higher number of simultaneous users. We show in figure (2) that RD code shows a better performance than other codes. For example the value of BER for the RD and MDW codes when the EB is 80 MHz is 1.44×10^{-63} and 1.78×10^{-38}, respectively. However, when the number of simultaneous users is 70, the MDW code gives better performance than RD and MQC codes as shown in figure (3). For example, the value of BER for the MDW code at EB = 80 MHz is 3.55×10^{-20}, while the BER of the RD code at the same value of Electrical Bandwidth is 5.3510^{-18}.

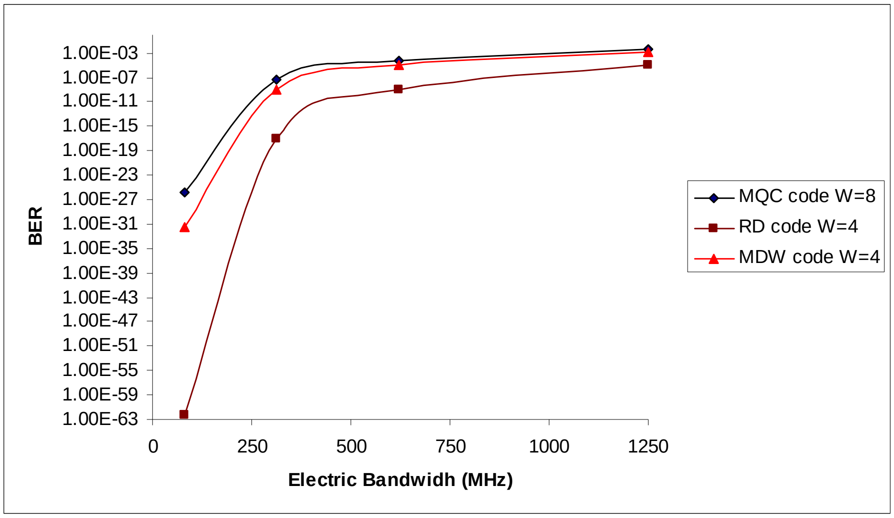

Fig. 2: BER versus EB for MDW, RD, and MQC codes when the number of users K = 35.

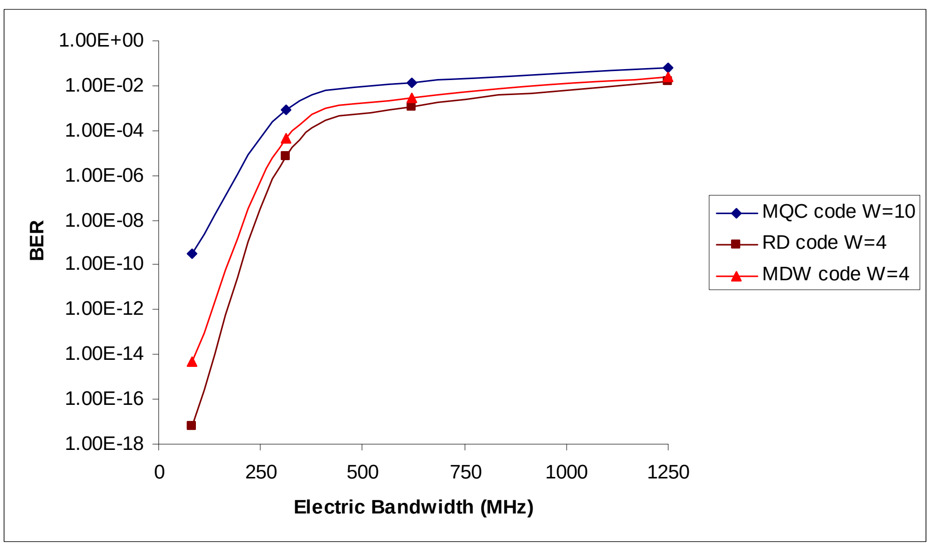

Fig. 3: BER versus EB for RD, MDW, and MQC codes when the number of users is K = 70.

Figure (4) shows the BER variations with *Psr* when number of simultaneous users is 35 and Electrical Bandwidth is 80 MHz We can observe from figure (4) when *Psr* value more than -20dBm RD code has a small BER compared with MDW and MQC codes, as a result the BER response for RD is better than MDW and MQC for same number of users. For example the value of BER of the RD code when *Psr* = -10 dBm is 3.99×10^{-63}, while the BER of the MDW code at the same number of active users and with -10dBm is 2.59×10^{-32}. However, when the number of simultaneous users is increased up to 70, the MDW code gives better performance than RD and MQC codes as shown in figure (5). For example the value of BER for MDW and RD codes at *Psr* = 0dBm is 3.55×10^{-20} and 5.35×10^{-18}, respectively. However, RD code is more suitable for SAC-OCDMA networks with low effective power of light source ($Psr\leq$ -10dBm) comparing with other codes.

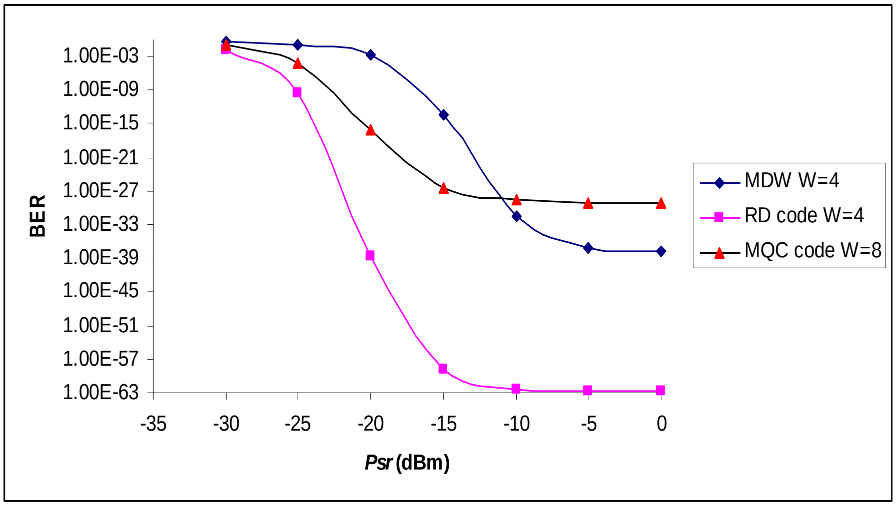

Fig. 4: BER versus *Psr* for RD, MDW and MQC codes when the number of users *K* = 35.

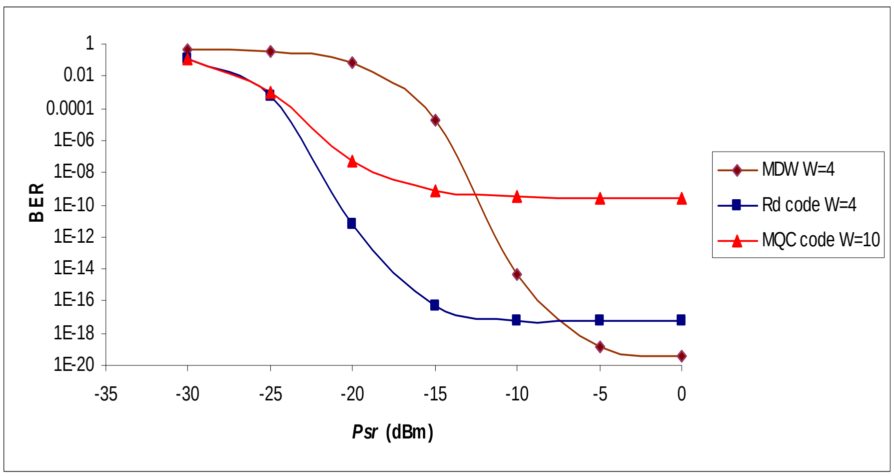

Fig. 5: BER versus Psr for RD, MDW and MQC codes when the the number of users *K* = 70.

II. Conclusions:

In this paper, we present the construction of three recent unipolar SAC-OCDMA codes and investigate these codes performances. The analytically evaluated of these three codes using different values of received power, electrical bandwidth, number of users, and the BER show that when the number of simultaneous users is a small for example *K*=35, the RD code gives better performance than MDW, and MQC codes. In contrast, if the number of active users is 70 the MDW gives a good performance comparing with the RD, and MQC codes. The advantages of the RD code comparing with the other codes are: shorter codes length, no cross-correlation at data segment, while the MDW code has many advantages such as: the efficient and easy code construction, ideal cross-correlation λ=1, and high SNR. These codes are considered the promising solution for next generation OCDMA networks.

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