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Development of new two-dimensional spectral/spatial code based on dynamic cyclic shift code for OCDMA system

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ABSTRACT

In this paper, a new two-dimensional spectral/spatial codes family, named two dimensional dynamic cyclic shift codes (2D-DCS) is introduced. The 2D-DCS codes are derived from the dynamic cyclic shift code for the spectral and spatial coding. The proposed system can fully eliminate the multiple access interference (MAI) by using the MAI cancellation property. The effect of shot noise, phase-induced intensity noise and thermal noise are used to analyze the code performance. In comparison with existing two dimensional (2D) codes, such as 2D perfect difference (2D-PD), 2D Extended Enhanced Double Weight (2D-Extended-EDW) and 2D hybrid (2D-FCC/MDW) codes, the numerical results show that our proposed codes have the best performance. By keeping the same code length and increasing the spatial code, the performance of our 2D-DCS system is enhanced: it provides higher data rates while using lower transmitted power and a smaller spectral width.

1. Introduction

In order to increase the number of simultaneous users sharing the same bandwidth, with high security level, optical code division multiple access (OCDMA) becomes a future promising technique for optical networks. It permits to attribute a specific sequence code for each user. It has many advantages such as: secure data transmission, simplicity of adding and deleting users, asynchronous access, ability to support multimedia services and dynamic bandwidth [1,2].

In the OCDMA system, the coding researches started with one dimensional (1D) coding. The multiple access interference (MAI) is considered as the major impairment in OCDMA system. In order to eliminate the MAI and increase the number of active users, we have to increase the code length [1,3]. The realization of long 1D code needs very narrow filter bandwidths and high power consumption, which makes difficult to realize OCDMA system even employing simple architecture [4].

Thanks to the entirely removing of MAI by using the subtraction technique, OCDMA systems using the spectral amplitude codes (SAC) with a fixed in-phase cross correlation equal to 1 becomes more popular [5].

Many 1D codes have been introduced: diagonal eigenvalue (DEU) has been proposed with ideal in-phase cross correlation to mitigate the MAI effect [6]. Abd et al. developed the dynamic cyclic shift Code (DCS). The results show that the MAI effect is reduced and the phase-induced intensity noise (PIIN) is eliminated. Its major conclusion was that DCS code offers a better performance than the standard SAC-OCDMA systems employing the conventional code and it is closer to any real practical environment [7].

The code length is the main drawback of the 1D code since it's tailored by the bandwidth of the broadband source (BBS) which limits the number of users [5].To increase the active users, to reduce the phase-induced intensity noise (PIIN) and to eliminate the MAI, various schemas of the 2D (spectral/spatial, time/spectral) codes have been introduced. For spectral/spatial encoding (S/S): Yang et al. developed the 2D-M-matrices codes based on 1D M-sequence [8]. In [9], Lin et al. proposed the 2D perfect difference

Abbreviations: 2D-DCS, two dimensional dynamic cyclic shift codes; MAI, multiple access interference; 2D, two dimensional; 2D-PD, 2D perfect difference; 2D-Extended-EDW, 2D Extended Enhanced Double Weight; OCDMA, optical code division multiple access; 1D, one dimensional; SAC, spectral amplitude codes; DEU, diagonal eigen value; DCS, dynamic cyclic shift Code; PIIN, phase-induced intensity noise; BBS, bandwidth of the broadband source; S/S, spectral/spatial encoding; 2D-MQC, 2D modified quadratic congruence codes; 1D-MDW, 1D modified double weight; 1D-FCC, 1D flexible cross correlation code; BLS, broadband light source; EOM, electro-optic modulator; FBG, fibers bragg grating; PD, photodiodes; PSD, power spectral density.

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(2D-PD) codes, the MAI has been eliminated by using the MAI cancellation property. In [10], Kadhim et al. proposed the 2D multi-diagonal (2D-MD) codes with suitable complexity receiver due to the property of zero cross correlation of 1D-MD code. In [11], Nurol et al. proposed the 2D Extended Enhanced Double Weight (2D-Extended-EDW) codes based on 1D-Extended-EDW code. For time/spectral encoding (T/S): The 2D modified quadratic congruence codes (2D-MQC) can suppress the MAI with the balanced detector structure at the receivers[12]. In [13], 2D hybrid code noted by 2D-FCC/MDW is the combination of 1D modified double weight (1D-MDW) code and 1D flexible cross correlation (1D-FCC) code. The results show that the system performance is improved by PIIN mitigation and MAI elimination.

Except systems based on 2D-MD codes with zero cross correlation, each transceiver of the 2D-OCDMA systems has not yet overcome the PIIN impact. In this paper, we propose the 2D dynamic cyclic shift codes (2D-DCS). By considering the influence of the PIIN, shot noise and thermal noise in the photo-detector, the system capacity is improved by mitigating PIIN and eliminating MAI. The analytical results show that the proposed code has a better performance than those published in [7,9,11,13].

The rest of this paper is organized as follows: The construction and properties of the 2D-DCS codes are presented in Section 2. The 2D-DCS OCDMA system description, including transmitter and receiver structures are shown in Section 3. System performance analysis is developed in Section 4. The numerical results are discussed in Section 5. Finally, the conclusion is given in Section 6.

2. 2D Spectral/spatial dynamic cyclic shift codes

2.1. 2D-DCS codes construction

According to [7], the 1D-DCS code is proposed for hybrid SCM-OCDMA networks. It has a short codelength and low MAI. The construction of the 1D-DCS code is based on the cyclic shift method and the Galois field. The 1D-DCS is characterized by (M, p, λ_c), where M is the code length, p is the code weight, and λ_c is the cross correlation value. It is represented by $M*M$ matrix which necessarily depends on M and p. The number of users K is equal to:

$$K = M = \sum_{i=1}^{p-1} 2^i + D \tag{1}$$

where D is the dynamic part ($D > 7$).

The construction process of the proposed code is described by the following steps according to [7]:

- Step 1: Generation of the S^i sequence for the first code C_i.

  The sequence S^i represents the positions of ones for the first sequence code C_1. It can be expressed as:

$$S^i = \begin{cases} (2^i)(modM) & i = 0, 1. \\ (2^i + S^{i-1})(modM) & i = 2, 3, \dots p-1. \end{cases} \tag{2}$$

  where S^i, M and p are the elements over the Galois field GF (M).
- Step 2: Generation of the first code sequence C_1.
  Basing on the generated sequence S^i, the first code sequence can be written by:

$$C_1(j) = \begin{cases} 1 & j = S^i \\ 0 & else \end{cases} \tag{3}$$

  where $j = 1, 2, \dots, M$.
- Step 3: Generation of the rest code sequence C_k.
  The rest of the code sequence C_k is determined by using the cyclic shift method as:

$$C_k(j) = \begin{cases} C_{k-1}(M) & j = 1 \\ C_{k-1}(j-1) & else \end{cases} \tag{4}$$

  where $k = 2, 3, \dots, M$.

The 2D-DCS code is generated from the 1D-DCS code and can be formed by using two sequences codes. Let $X = [x_0, x_1, \dots, x_{M-1}]$ and $Y = [y_0, y_1, \dots, y_{N-1}]$ be two codes sequences of 1D-DCS which have $M = \sum_{i=1}^{p_1-1} 2^i + D_1$ and $N = \sum_{i=1}^{p_2-1} 2^i + D_2$ as code lengths, where p_1 and p_2 are their code weights, D_1 and D_2 are their dynamic parts, respectively.

An example for two different 1D-DCS sets X and Y with $p_1 = 3$, $p_2 = 2$ and $D_1 = D_2 = 8$ is shown in Table 1, where Pos represents the positions of ones in each code sequence.

Let X_g and Y_h are the gth and hth cyclic shifted versions of X and Y, respectively, where X_g ($g = 0, 1, \dots, M-1$) is the spectral code sequence and Y_h ($h = 0, 1, \dots, N-1$) is the spatial code sequence. The 2D-DCS code can be formed by [9,14]:

$$A_{g,h} = Y_h^T X_g \tag{5}$$

The 2D-DCS codes of the above X and Y sequences are shown in Table 2.

The code matrix $A_{g,h}$ is represented by the pair (a_i,b_j) which represents the ones position. Where $i = 1, 2, \dots, N$ and $j = 1, 2, \dots, M$.

2.2. 2D-DCS codes properties

In order to obtain the cross-correlation of the 2D-DCS code, we define four characteristic matrices $A^{(d)}$ [9,14], where $d = 0, 1, \dots, 3$.

Table 1
1D-DCS CODE SETS X ($M = 14$, $p_1 = 3$) AND Y ($N = 10$, $p_2 = 2$).

$M = 14$, $p_1 = 3$		$N = 14$, $p_2 = 3$	
X_j	Pos of X_j	Y_i	Pos of Yi
X_1 = {11000100000000}	Pos_1 = [1;2;6]	Y_1 = {1100000000}	Pos_1 = [1;2]
X_2 = {01100010000000}	Pos_2 = [2;3;7]	Y_2 = {0110000000}	Pos_2 = [2;3]
X_3 = {00110001000000}	Pos_3 = [3;4;8]	Y_3 = {0011000000}	Pos_3 = [3;4]
X_4 = {00011000100000}	Pos_4 = [4;5;9]	Y_4 = {0001100000}	Pos_4 = [4;5]
X_5 = {00001100010000}	Pos_5 = [5;6;10]	Y_5 = {0000110000}	Pos_5 = [5;6]
X_6 = {00000110001000}	Pos_6 = [6;7;11]	Y_6 = {0000011000}	Pos_6 = [6;7]
X_7 = {00000011000100}	Pos_7 = [7;8;12]	Y_7 = {0000001100}	Pos_7 = [7;8]
X_8 = {00000001100010}	Pos_8 = [8;9;13]	Y_8 = {0000000110}	Pos_8 = [8;9]
X_9 = {00000000110001}	Pos_9 = [9;10;14]	Y_9 = {0000000011}	Pos_9 = [9;10]
X_{10} = {10000000011000}	Pos_{10} = [1; 10;11]	Y_{10} = {1000000001}	Pos_{10} = [1;10]
X_{11} = {01000000001100}	Pos_{11} = [2;11;12]		
X_{12} = {00100000000110}	Pos_{12} = [3; 12;13]		
X_{13} = {00010000000011}	Pos_{13} = [4; 13;14]		
X_{14} = {10001000000001}	Pos_{14} = [1; 5; 14]		