

# Performance Analysis of 1D and 2D in Optical Code Division Multiple Access

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**Abstract**— Optical code division multiple access system (OCDMA) achievements the advantages of CDMA and Optical communication. Optical code-division multiple-access is proposed as a natural solution to achieving asynchronous, high-speed connectivity in a local area network environment. Optical CDMA is shown to be competitive with other networking technologies such as WDMA and TDMA, but has the benefit of more flexibility, simpler protocols, and no need for centralized network control. OCDMA encoding/decoding process provides a high level of security which is directly implemented in the physical layer. In OCDMA, type of coding technique plays a major factor that influencing its performance. This paper presents performance analysis of two important OCDMA coding techniques namely – 1-D and 2-D codes. Firstly performance analysis of various 1-D codes namely Walsh Hadamard codes (WHC), Optical orthogonal codes (OOC) and Zero cross correlation (ZCC) has been carried out. Secondly performance analysis of 2-D Wavelength/Time (W/T) codes has been carried out. The performance metrics on which the various codes performance has been measured are: different data formats (NR and RZ), increasing fiber distance, amount of received power, increasing the bit rate and number of simultaneous active user. Simulated results show that among 1-D codes ZCC codes provides the best overall performance over OOC and WHC. 1-D codes provide low bit error rate (BER) but they possess high temporal length. To overcome this, 2-D codes have been used which have higher cardinality than 1-D code.

**Key words:** OCDMA, BER, Bit Rate, MAI, NRZ, RZ WHC, OOC, ZCC; W/T, WDMA, TDMA, 2D, 1D

## I. INTRODUCTION

OCDMA system is being used for high quality video transmission and in LANS due to its large bandwidth and less attenuation [1]. It has many advantages over the conventional optical systems such as more privacy to each and every user, flexibility in channel allocation. Further it can allow multiple users to access the network asynchronously and simultaneously. Now the network capacity is not limited but it's highly scalable.

An OCDMA system shares a common strategy of distinguishing data channels by a specific optical code rather than a wavelength or a time slots. An encoding operation optically transforms each data bit before transmission whereas suitably designed receivers isolate channels by code-specific detection. The Figure-1 shows an OCDMA network with N pairs of transmitters and receivers. OCDMA is a technique that allows several users to transmit their data simultaneously over the same optical fiber and for that we provide distinguishable and unique code to every user at the transmitter and at the receiver, the reverse decoding operation is performed to recover the original data [2]

## II. TYPES OF CODES

In OCDMA system, different types of optical codes have been proposed and studied for various OCDMA technologies. The major types of codes that are available for OCDMA system are:

### A. One Dimensional (1-D) Codes

The One-dimensional codes spread either in time [3] or in frequency [4]. The set is constructed so that it should follow the following two properties [5].

The Auto-Correlation Property

; for any  $x \in C$  and any integer  $\tau$ ,  $0 < \tau < n$ . (1)

The Cross-Correlation Property

; for any  $x \neq y \in C$  and any integer  $\tau$ . (2)

There are various 1-D codes which can be used to implement an OCDMA system like:

#### 1) Walsh Hadamard Codes

An N-element Hadamard code consist of a row from  $N \times N$  orthogonal Hadamard matrix, which has (1,-1) valued binary entries. The  $N \times N$  Hadamard matrix  $H_M$  where  $N = 2^M$  [6] is generated by the code matrix:

The Unipolar Hadamard matrix  $H_M$  must follow the following properties: (i) Value of  $M$  should be greater than or equal to 2. (ii) The Code length  $L = 2^M$  (iii) The Code Weight  $W = 2^{M-1}$  (iv) No of users  $K = 2^M - 1$  (v) The cross-correlation ratio is = 2.

The sequence (1, 0) is a unipolar Hadamard code for example, for  $Z = 4$

This code can support  $2^M - 1$  number of simultaneous users.

#### 2) Optical Orthogonal Codes (OOC)

The following procedure [7] yields a class of optimizing orthogonal codes for  $\lambda_a = \lambda_c = 1$  for variable code length  $n$  and weight  $w$ . This class is denoted by the notation  $\{n, w, s\}$ , where  $s$  represents the number of simultaneously active sources.

- (1) Construct a matrix  $P_1$  of  $w \times (w - 1)$  rows and  $w$  columns whose elements form the following design:
- (2) To create a vector  $E = \langle e_1, e_2, \dots, e_w \rangle$  by first randomly selecting  $w-1$  integers, without replacement, from  $[1, n-1]$  whose sum is less than  $n$ ; then setting the first  $w-1$  entries of  $E$  to these integers, and setting the entry:  $e_w = n - \sum_{i=1}^{w-1} e_i$
- (3) Now perform the matrix multiplication:  $P_1 \times E^T$ , where  $E^T$  is the transpose of  $E$ .
- (4) If a vector obtained from  $P_1 \times E^T$  yields distinct elements, accept  $E$  as a code.

#### 3) Zero Cross Correlation Codes (ZCC)

The ZCC code can be represented in a matrix of  $R \times C$  where  $R$  (row) represents the number of users and  $C$  (column) represents the minimum code length. The matrix contains the binary coefficients. A basic ZCC code and can be shown as:

It can be seen that the code length  $C$  also increases

as the value of R is increased. The basic matrix is mirrored diagonally to increase R. Here 1s represents the position of spectral component or chip position in the code length. The relationships between the mapping process M, R and C is given by:  $R = 2^M$  and  $C = 2^M$ . Thus  $C = R$ . The ZCC shown above has the fixed code weight that is 1. In order to have a flexible code weight i.e. to increase w, some code transformation steps need to be followed [8]. The transformation steps are:

C consists of duplication matrix from w-1 matrix, D consists of diagonal pattern of [m x n] with alternate column of zeros matrix [m x n].

*B. Two dimensional (2-D) codes*

MWOOCs such as modification of 1D OOCs, application of error correction codes to the optical domain, or algebraic coding methods. In all cases, however, the codes were arbitrarily restricted to have a single pulse per row in the matrix. This limited the code cardinality and necessitated equal weight for all signature sequences. As we show in the following section, relaxing the single pulse per row constraint will lead to a more flexible family of MWOOCs that may allow for differentiated levels of service at the physical layer in a CDMA LAN. The Two-dimensional W/T codes can be spread in time with frequency. A technique which is based on the “folding” of spanning rulers or optimum Golomb rulers [9] is used to generate pseudo orthogonal matrix codes. An optimum Golomb ruler or spanning ruler is a (0, 1) pulse sequence where the distances between any pulses is a non-repeating integer. The optimum Golomb ruler **g(1,7)** of cardinality 1, weight 7, and length 26 [10] is shown in Figure-2. Three shifted versions of the ruler were made. To make up the code dimension (CD) of 32 filler zeros can be used.

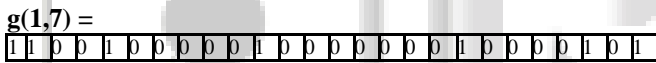


Fig. 2: Optimum Golomb ruler g(1,7).

The CD is determined as follows [11]: The Golomb rulers are shifted which indicates that the result should be a matrix of dimensions  $CD = r * C$ , where  $r * C > L$ . Here “r” is the number of rows, “C” is the number of columns and L is the length of the Golomb ruler. Then possible shifts are  $r * C - L$ ; the number of new matrices depends on the two parameters. First is initial Golomb ruler length L and second is the number of shifts permitted by the product  $r * C$ . In order to assure that the matrix code set size M is equal to the number of rows in the matrices the following condition should be fulfilled.

$r * C - L \geq r - 1$  (10) The ruler-to-matrix transformation [10] enhances cardinality (code set size) while preserving the OOC property. On the other hand this transformation increases the cardinality (n versus  $n * r$ ) from one to four. The concept of folded optimum Golomb rulers can be extended by using sets containing more than one optimum Golomb ruler to target matrices with eight time slots and eight wavelengths. A set of optimum Golomb rulers (**g1(4,4)**, **g2(4,4)**, **g3(4,4)**, and **g4(4,4)**) of cardinality four and weight four [10] is shown in Figure-3.

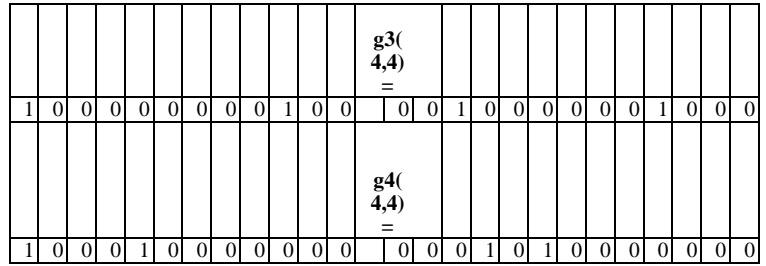
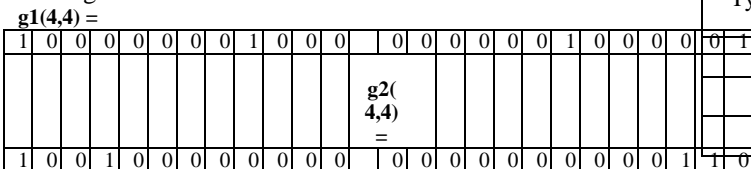


Fig. 3: Golomb rulers g1(4,4), g2(4,4), g3(4,4) and g4(4,4).

Wavelength (W)	Time Slots (s)			
	1	2	3	4
<b>1</b>	<b>1,9,17,25</b>	1,14,29	19,24,26	1,7,10,11,20,32
2	2,10,18,26	<b>2,15,17,30</b>	20,25,27	2,8,11,12,21
3	3,11,19,27	3,16,18,31	<b>1,21,26,28</b>	3,12,13,22
4	<b>4,9,12,20,28</b>	4,19,32	2,22,27,29	4,13,14,23
5	5,10,13,21,25,29	5,20	3,23,28,30	5,14,15,24
6	6,11,14,22,26,30	6,21	4,17,24,29,31	6,15,16
7	7,12,15,23,27,31	7,17,22	<b>5,9,18,30,32</b>	7,16
8	8,13,16,24,28,32	8,18,23,25	6,9,10,19,31	8

Table 1: 32 Pseudo orthogonal (PSO) Matrix Codes Interpreted as W=T Matrix Codes.

The PSO matrices are converted to W/T codes by associating the rows of the PSO matrices with wavelength and the columns with time-slots, as shown in Table 1. The matrices M1... M32 are numbered 1... 32 in the table, with their corresponding wavelengths and time-slots. The codes M1 and M9 are shown bold in table. The code M1 is represented as ( $\lambda_1; \lambda_1; \lambda_3; \lambda_1$ ) and M9 as ( $\lambda_1, \lambda_4; 0; \lambda_7, \lambda_8; 0$ ); here the semicolons separate the timeslots in the code. In code M9 there are two wavelengths ( $\lambda_1, \lambda_4$ ) in time-slot 1 and no wavelength is allotted in time-slot 2. M1 shows extensive wavelength reuse, and codes M9 shows extensive time-slot reuse. Due to extensive wavelength and time-slot reuse these matrix codes have a high cardinality.

III. SIMULATION

1-D codes i.e. WHC, OOC and ZCC codes and 2-D W/T codes have been simulated. Various parameters used for these simulations are given in Table-2.

Parameters	Value 1-D	Value 2-D
<b>Optical Source specification</b>		
Continuous wavelength source	1549.7 nm – 1550.8 nm	1543.74 nm – 1549.34 nm
Continuous wavelength source power	10 dBm	10 dBm
<b>Optical fiber</b>		

Type of optical fiber	The ITU-T G.652 standard single mode optical fiber.	
Distance	1Km - 40Km	1Km - 60Km
Optical Filter specifications		

BPF cut off wavelengths $\lambda_1 - \lambda_{12}$	1549.7 nm – 1550.8 nm	1543.74 nm – 1549.34 nm
Wavelength	.1nm	.8nm
<b>Time Delay Specifications</b>		
Delay	NA	1ms – 4ms
<b>PIN Photodetector specifications</b>		
Dark Current	1nA	1nA

Table 2: Simulation parameters used for the simulation of 1-D and 2-D codes.

#### IV. RESULTS AND DISCUSSIONS

The performance evaluation of the OCDMA system using various 1-D coding techniques has been checked with the help of various performance metrics which are: (i) Different data formats (NRZ and RZ) and amount of received power with increasing fiber distance. (ii) Number of simultaneous active user and increasing the bit rate with BER. For this purpose fiber length is varied from 1Km to 40 Km, no. of users were varied from 1 to 4 and bit rate is varied from 1Gbps to 10 Gbps other parameters like source power and attenuation are kept constant. The comparison of various 1-D codes has been shown from Figure-4 to 7.

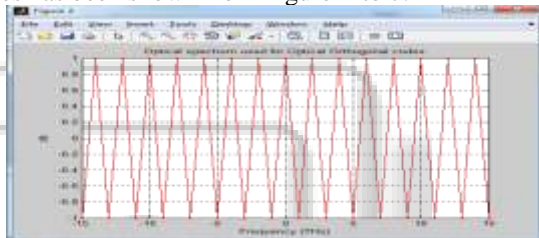


Fig. 1: Optical spectrum used for OOC Code

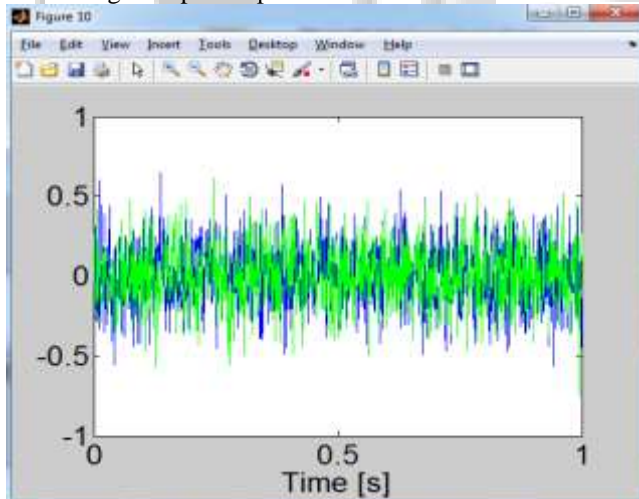


Fig. 2: Eye Diagram 1-D Codes.

In the similar way the performance evaluation of the OCDMA system using W/T 2-D coding techniques has been checked with the help of various performance metrics which are: (i) Different data formats (NRZ and RZ) and amount of received power with increasing fiber distance. (ii) Number of simultaneous active user and increasing the bit rate with BER. For this purpose fiber length is varied from 1Km to 60 Km, no. of users were varied from 1 to 4 and bit rate is varied from 1Gbps to 10 Gbps other parameters like source power and attenuation are kept constant. The results of various 2-D codes have been shown from Figure-8 to 11.

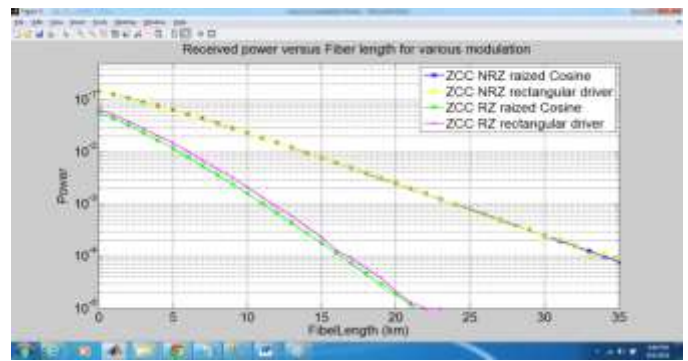


Fig. 3: Received power versus fiber length for ZCC code

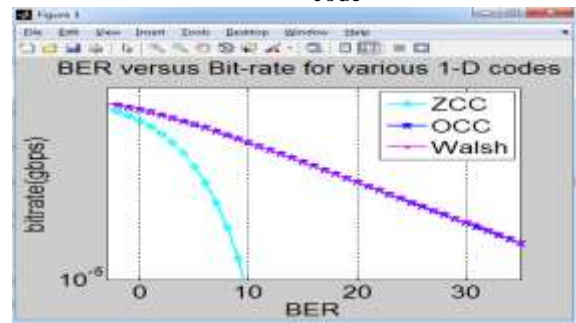


Fig. 4: BER vs. Number of simultaneous active users for W/T 2-D Codes.

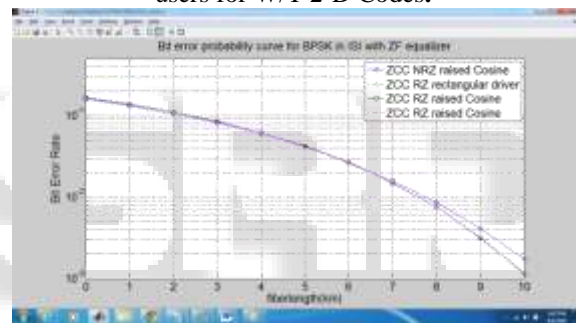


Fig. 5: BER vs. Fiberlength for 2D and 1D code users for W/T 2-D Codes.

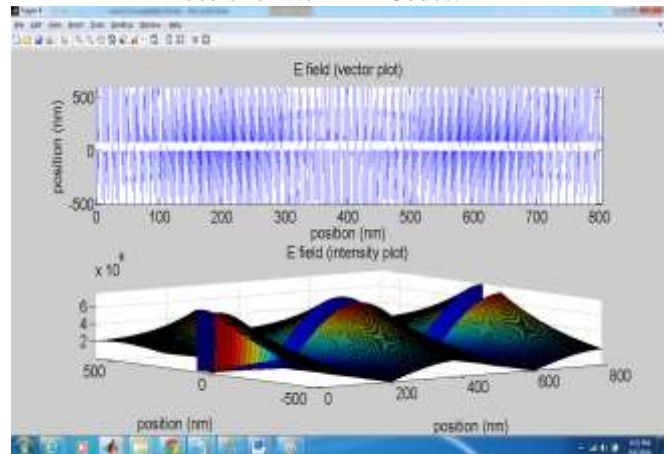


Fig. 6: BER vs. Number of position active users for W/T 2-D Codes.

#### V. CONCLUSION

The performance analysis of various 1-D codes in OCDMA system is carried out. The comparison of Walsh Hadamard codes, OOC and ZCC using various data formats revealed that the NRZ modulation format has the edge over RZ modulation format in OCDMA systems.

Also it's found that the NRZ has lowest BER value and better system performance. Hence, NRZ data format can be recommended for the distances suitable for local area networks using OCDMA systems at high bit rates. The analytical results revealed that ZCC code has a superior code property of zero cross correlation. It can be seen from the values of the BER and the received power, that the ZCC code gives the best performance compared to Walsh Hadamard and OOC codes. Hence, it is concluded that the ZCC codes are most suitable to be employed in the OCDMA systems using NRZ data format.

The performance analysis of 2-D wavelength/time codes for OCDMA is also carried out. A technique based on folding of Golomb ruler for the construction of 2-D is described. It has been observed that cardinality of 2-D codes is higher than 1-D codes. The eye diagram degrades and the BER increases as the number of active users increases. The BER further increases with the increase in number of transmitting users when two codes are used at receiver end.

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