

# Comparison of Non Zero Cross- Correlation and Diagonal Identity Matrix codes in Optical Code Division Multiplexed System

Sarnjit Kaur, Gurmeet Kaur, Beant Kaur

**Abstract**— In this work, an optical code division multiplexing system using diagonal identity codes is proposed. Total 10 users are considered at 5 Gbps bit rate and channel spacing is fixed to 100 GHz. Diagonal identity matrix codes can be designed for any number of users with weight greater than 2. It has zero cross correlation and very simple design with less multiple access interference. Performance analysis of proposed system is accomplished for different link lengths, users and comparison with different existing codes has been done.

**Index Terms**— Optical code division multiple access, Diagonal identity matrix, Non zero cross correlation, Multi-diagonal, Modified frequency hopping, Random diagonal.

## I. INTRODUCTION

Internet demands are increasing globally at very high pace and optical communication systems require high capacity and high speed systems [1]. Optical code division multiplexing is a prominent technique to provide asynchronous access, flexibility, simple network architecture, security, network management, capacity to handle a large number of users. Local area networks and metropolitan networks are using optical OCDMA networks to fulfil their demands [2]. Spectral amplitude coding is an important type of OCDMA systems and considered as most efficient method [3]. However, multiple access interference and phase induced noises are severe drawbacks in OCDMA coding. MAI due to multiple users can be lowered by using substations detection but PIIN remains the same [4]. In order to quell the effects of PIIN and MAI, optical codes with zero cross-correlation are required. Many optical codes are reported till now such as flexible cross-correlation (FCC) [5], multi-diagonal (MD) [6], dynamic cyclic shift (DCS) [7], partitioned partial prime (PPP) [8], random diagonal (RD) [9], modified frequency hopping (MFH) [10], modified quadratic congruence (MQC) [11] and modified double weight (MDW) [12]. But code lengths in these codes are very long, limitation in increasing users, and cross correlation increase. Also balanced subtraction detection in SAC OCDMA systems is a great issue. Recently a new non zero cross-correlation code is designed [133]. Distance reach of NZCC system was less and therefore optimal coding is required. Therefore in this work, an optical code division multiplexing system using diagonal

identity codes is proposed at 5 Gbps with zero cross-correlation

## Code Construction of DIM

From the existing code schemes it is evident that the cross-correlation is a major security issue among multiple users which makes the system vulnerable to eavesdropper. To remove the existing limitations, a high speed new security enhanced SAC-OCDMA code has been proposed with zero cross correlation and flexibility to choose the desired code weight which is Diagonal Identity Matrix code.

The Generalized code construction algorithm is explained below. The code construction steps and algorithm is described as:

**Step 1:** Choose the value of number of users (K) and weight of code  $W=2, 3, 4 \dots, N$  for every user.

**Step 2:** Calculate the length of the code as:

$$L = K \times W \dots \dots \dots (1)$$

**Step 3:** Size of basic balanced matrix

$$I_B = 2 \times W \text{ (balanced)} \dots \dots \dots (2)$$

**Step 4:** Basic matrix of order  $Y \times Z$  is constructed for any number of users as:

$$I_B = \begin{pmatrix} UE \\ LE \end{pmatrix} = \begin{bmatrix} \left[ \frac{W}{2} \right] 1's & [W-2] 0's \\ \left[ \frac{W+2}{3} \right] 0's & \left[ \frac{W+1}{2} \right] 1's \end{bmatrix}_{Y \times Z} \dots (3)$$

Where UE is Upper End and LE is Lower End

**Step 5:** The complete code set is represented by matrix M of size  $K \times L$  for K users. The construction of M involves 3 steps in which an intermediary matrix  $M^1$  is first constructed.  $I_B$  is repeated K -1 times in M as shown below

$$M^1 = \begin{bmatrix} UE & \dots & LE \\ LE & UE & \vdots \\ \dots & LE & \dots \\ & \dots & UE \\ \dots & \dots & LE & UE \end{bmatrix} \dots \dots \dots (4)$$

Repeat the process for  $K \times L$  times as shown in matrix  $M^2$

$$M^2 = \begin{bmatrix} UE & \dots & LE \\ LE & UE & \vdots \\ \dots & LE & \dots \\ & \dots & UE \\ \dots & \dots & LE & UE \end{bmatrix}_{K \times L} \dots (5)$$

Fill zeros in the empty spaces of matrix  $M^2$  to make final matrix M as given below

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$$M = \begin{pmatrix} UE & 00 & 00 & 00 & 00 & LE \\ LE & UE & 00 & 00 & 00 & 00 \\ 00 & LE & UE & 00 & 00 & 00 \\ 00 & 00 & LE & UE & 00 & 00 \\ 00 & 00 & 00 & LE & UE & 00 \end{pmatrix}$$

$K \times L \dots (6)$

Autocorrelation in a code defines the number of 1's existing within a code. Higher autocorrelation leads to better signal to noise ratio at the receiver side and better signal quality but on the other side it can lead to interference between the bandwidths of number of bits due to which the desired quality of the signal deteriorates.

Auto-correlation:  $Ax, x = \sum_{n=0}^{N-1} C[x]C[x]$  where  $0 < m < N-1$   
 Cross correlation:  $Cx, y = \sum_{n=0}^{N-1} C[x]C[y]$  where  $0 < m < N-1$

Cross-correlation occurs between the codewords of two different users. It is basically an issue in existing coding schemes as it leads to multiple access interference between number of users and makes it possible for the eavesdropper to detect the wavelengths of the code of the authorized data. DIM codes have auto-correlation of 2 and cross correlation of 0. The following flow diagram i.e. Figure 1 depicts how the Diagonal Identity Matrix code is constructed and implemented.

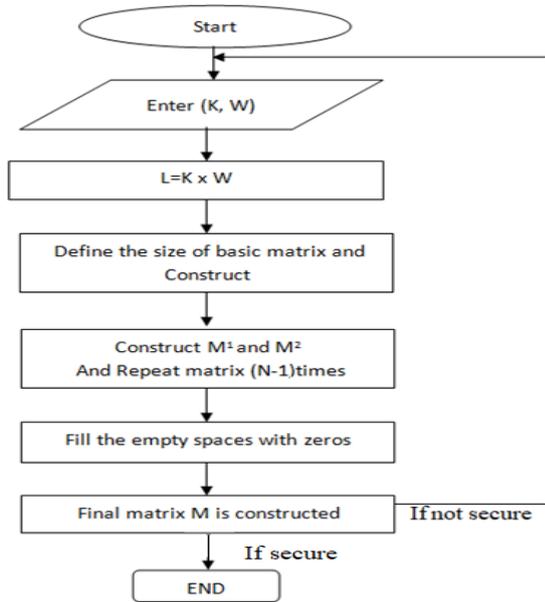
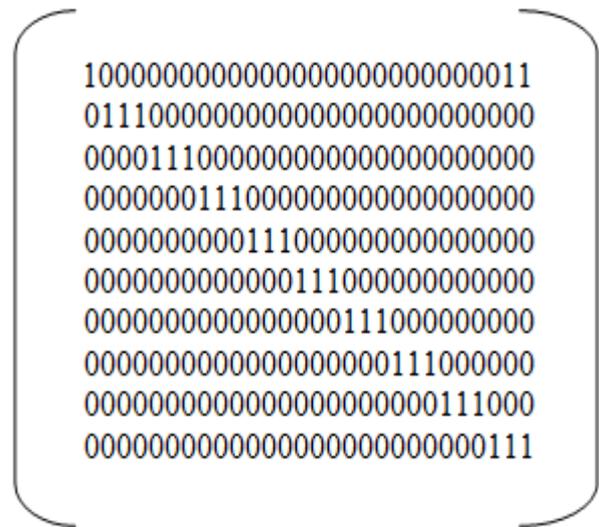


Fig.1. Flow chart of Diagonal identity matrix codes

## II. SYSTEM SETUP

Figure 2 represents the optical code division multiplexing system based on DIM codes for 10 users. A broadband laser array is deployed for the 10 users having 30 wavelengths because weight of DIM is taken as 3. Power at each wavelength is fixed to 0 dBm and laser linewidth is 10 MHz. Wavelengths are combined according to given matrix which is developed from the DIM code construction as shown below



- Wavelengths for
- User 1= 193.1 THz, 195.9 THz, 196 THz
  - User 2= 193.2 THz, 193.3 THz, 193.4 THz
  - User 3= 193.5 THz, 193.6 THz, 193.7 THz
  - User 4= 193.8 THz, 193.9 THz, 194 THz
  - User 5= 194.1 THz, 194.2 THz, 194.3 THz
  - User 6= 194.4 THz, 194.5 THz, 194.6 THz
  - User 7= 194.7 THz, 194.8 THz, 194.9 THz
  - User 8= 195 THz, 195.1 THz, 195.2 THz
  - User 9= 195.3 THz, 195.4 THz, 195.5 THz
  - User 10= 195.6 THz, 195.7 THz, 195.8 THz

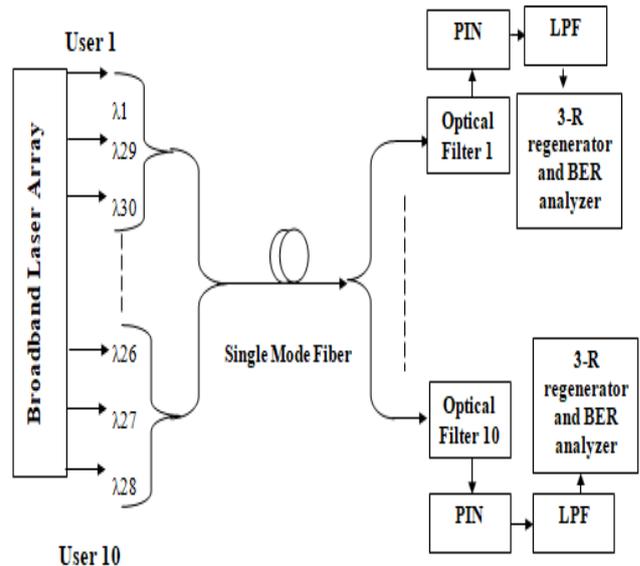


Fig.2. Block diagram of proposed OCDMA system using DIM codes for 10 users at 5Gbps

These wavelengths are multiplexed with 3 x 1 multiplexer according to the selected wavelengths as code suggested. These multiplexed wavelength in the pair of three wavelengths are given to data modulation section where binary data is generated and pulse shaping is done through non return to zero modulation format and electrical pulse is converted into optical by using intensity modulator mach zehnder modulator. Simulation parameters of the proposed work are given in Table 1.

Table I Simulation Parameters of Proposed 5 Gbps OCDMA-DIM system

Parameters	Values
Data rate	5 Gbps
Users	10
SAC code	Diagonal identity matrix codes
Cross correlation	0
Weight	3
Code length	30
Distance	30 km - 110 km
Channel spacing	100 GHz
Input power	0 dBm/channel
External amplifier	NA

This is completed for all 10 users and then users are multiplexed and fed to single mode fiber having length 100 km. No amplifier is used in this work and after transmission through SMF, signal is de-multiplexed through filters of specific frequency according to the code used. Optical filters are followed by photo-detector, low pass filter, 3-R regenerator, and BER analyzer.

### III. RESULTS AND DISCUSSION

Performance analysis of optical code division multiplexing incorporating diagonal identity matrix codes is carried out. Optical spectrum analyzer is a tool to represent the carrier spectrum's power and frequency of operation. Power at each carrier is 0 dBm and after insertion losses of the modulator, are represented Figure 3.

Investigation of proposed optical code division multiplexing is observed at different distances of single mode fiber in terms of BER. Distance is varied from 30 km to 110 km and comparison between DIM codes and NZCC codes has been done as shown in Figure 4 and mathematical analysis has been shown in Table 2. It has been perceived that distance enhancement brings the change in BER of both codes and BER decreases. Performance in terms of BER is better in case of DIM codes as compared to NZCC codes. [13]

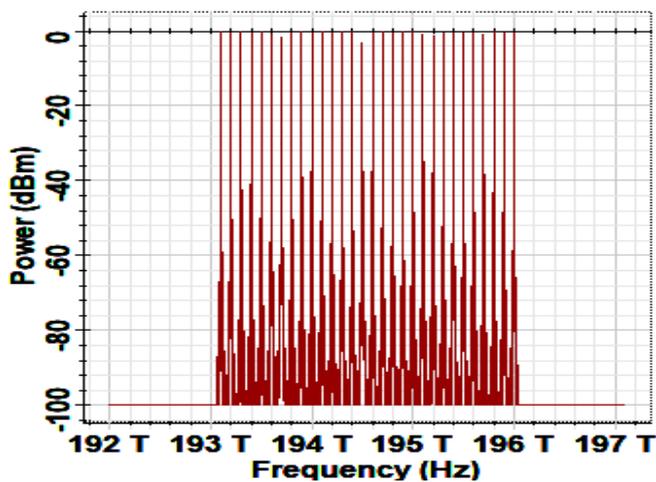


Fig.3. Representation of all wavelengths on Optical analyzer

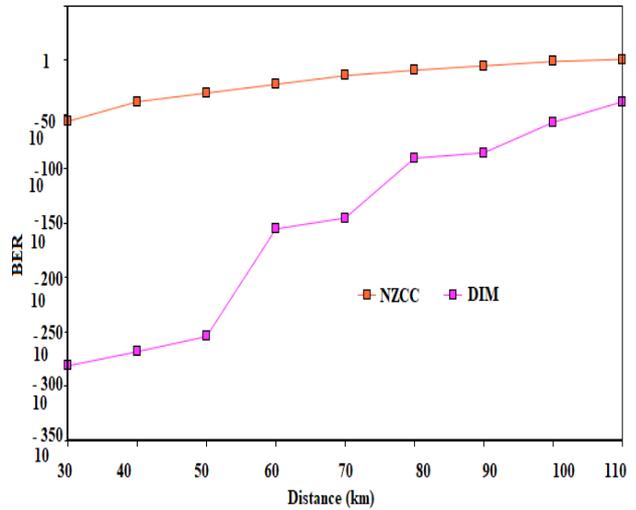


Fig.4. Performance comparisons of NZCC codes and DIM codes

Table II Values of BER at different distances for NZCC and DIM codes

Distances(Km)	DIM	NZCC
s30	$10^{-281}$	$10^{-55}$
40	$10^{-268}$	$10^{-48}$
50	$10^{-254}$	$10^{-35}$
60	$10^{-155}$	$10^{-30}$
70	$10^{-145}$	$10^{-15}$
80	$10^{-90}$	$10^{-10}$
90	$10^{-85}$	$10^{-4}$
100	$10^{-57}$	$10^0$
110	$10^{-38}$	$10^0$

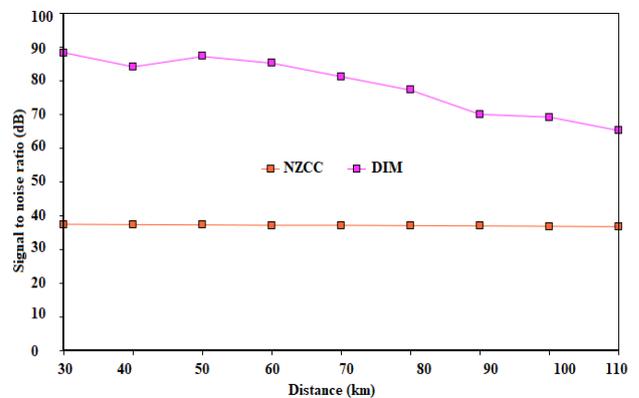


Fig.5. Variation of signal to noise ratio versus distance

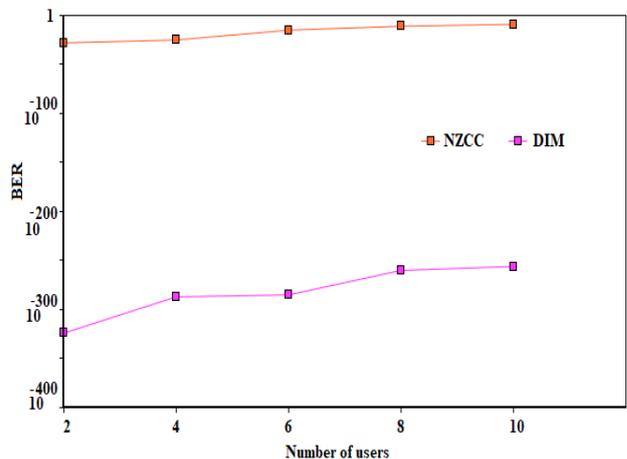


Fig.6. Variation of BER with number of users

## Comparison of Non Zero Cross- Correlation and Diagonal Identity Matrix codes in Optical Code Division Multiplexed System

Signal to noise ratio in optical communication systems is prominent parameter. More is the signal power, more is the SNR and less is the noise. SNR is analyzed at different distances for NZCC and DIM codes and results revealed that with the increase in distance, SNR tends to decrease but SNR is higher in DIM codes.

Table 3 and Figure 5 represents the effects of the users on the NZCC and proposed DIM codes. It has been in this work observed that increase in the users, increase the multiple access interference among the users which degrades with the performance of the system. Out of DIM and NZCC codes DIM codes performs better because they have less interference, which has been proved.

Table III Values of BER at different users

Users	DIM	NZCC
2	$10^{-324}$	$10^{-28}$
4	$10^{-287}$	$10^{-25}$
6	$10^{-285}$	$10^{-15}$
8	$10^{-260}$	$10^{-11}$
10	$10^{-256}$	$10^{-9}$

Eye diagrams are the depiction of average number of bits such as 0 or 1 in one fixed time slot. This is the final component to represents the Q factor and BER of the received signal. It also display the eye opening, extinction ratio, jitter and eye closer. Figure 6 (a) and 6 (b) shows the eye diagram of DIM codes at 50 km and 100 km respectively. It is observed that eye opening is more in case of 50 km and less in 100 km because of the attenuation, dispersion and scattering effects. Q factor of DIM codes decreases as distance moves from 50 km to 100 km.

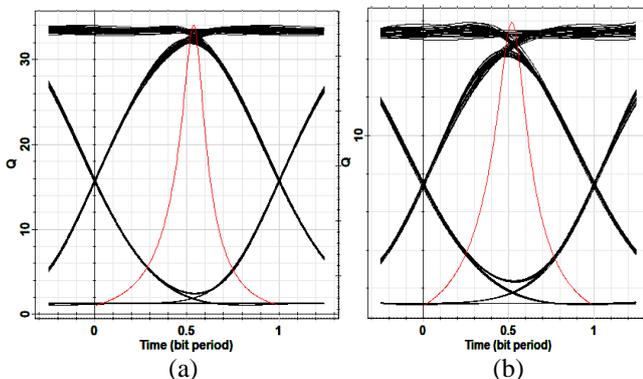


Fig.7. Eye diagrams of DIM code at (a) 50 km (b) 100 km

### IV. CONCLUSION AND FUTURE SCOPE

Optical code division multiplexing is widely used in optical communication systems due to its high speed operation and capacity to cater multiple users at the same time. In this work, an OCDMA code with zero cross correlation is investigated using diagonal identity matrix codes. Data rate of 5 Gbps is considered for 10 simultaneous users over 110 km link distance and comparison has been done with NZCC codes. Performance of the system is analyzed for Q factor, BER and SNR. It is observed that proposed DIM codes achieved 110 km link distance within acceptable range of BER (10<sup>-38</sup>) and NZCC worked for only 80 km. Cost effective direct detection using single optical filter and photodetector is employed in this work. DIM codes have enhanced performance due to high

bandwidth efficiency. Further, in order to operate proposed system in high speed systems, data rate of the proposed system is enhanced to 10 Gbps. Results revealed that DIM codes at 10 Gbps can work for 100 km in the presence of 10 users. It can be extended by using more users in this work.

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