Performance Analysis of Optical CDMA System using Generalized Code and Zero Cross Correlation Code

A thesis is

Submitted by

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Certificate

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Declaration

I, Sharwan Kumar Jangid, hereby declare that this thesis submission titled as **Performance Analysis of Optical CDMA System using Generalized Code and Zero Cross correlation Code** is my own work and that, to the best of my knowledge and belief.

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Sharwan Kumar Jangid

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Dedicated to my beloved

Parents, wife and baby Mitansh

For their love, endless support, encouragement

& sacrifices

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–Sharwan Kumar Jangid

List of Abbreviations

OCDMA	–	Optical Code Division Multiple Access
SAC	–	Spectral Amplitude Coding
LED	–	Light Emitting Diode
ZCC	–	Zero Cross Correlation
BER	–	Bit Error Rate
SNR	–	Signal to Noise Ratio
DD	–	Direct Detection
MZM	–	Mach – Zehnder Modulator
1–D	–	One Dimension
2–D	–	Two Dimension
DS	–	Direct-sequence coding
SSC	–	Spread space coding
TPC	–	Temporal phase coding
SPC	–	Spectral Phase Coding
HC	–	Hybrid Coding
WHTS	–	Wavelength Hopping Time Spread Coding

List of Symbols

nm	–	Nanometer
L	–	Length of Code
dB	–	Decibel
N	–	No. of Users
W	–	Weight of Code
Psr	–	Effective Received Power at Receiver
λ	–	Wavelength
$\Delta\upsilon$	–	Line width of broadband
B	–	Electrical bandwidth
η	–	Quantum Efficiency
T_n	–	Receiver noise temperature
e	–	Electron charge
h	–	Planck's constant
k_b	–	Boltzmann's constant
R_L	–	Receiver load resistor

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Abstract

The Optical Code Division Multiple Access (OCDMA) system assigns different codes to each user and the all user can access same transmission medium asynchronously and simultaneous. Due to this property, OCDMA systems are most suitable for those networks, where traffic is asynchronous such as local area network.

The OCDMA system is affected by Multiple Access Interference (MAI), which degrades the system performance, when large no. of users are active in the system. The MAI (Multiple Access Interference) is completely removed in Spectral Amplitude Coding – Optical code division multiple access technique (SAC-OCDMA) by using ideal in-phase cross correlation property of codes. SAC-OCDMA System provide codes in spectral domain.

For the SAC- OCDMA, many coding techniques have been developed such as Modified quadratic congruence code for prime weights, Khazani – Syed (KS) code, MDW(Modified double weight) code & EDW (Enhanced double weight code) and many others.

In this project performance of the SAC-OCDMA System is analysed using Generalized Code and Zero Cross Correlation Code.

The generalized Codes are constructed using a generalized code construction algorithm for the weight greater than 2. This algorithm provides same code length increment for additional user. It maintain cross correlation value almost one ($\lambda_c \leq 1$). Length and other properties are similar to MDW & EDW codes where as the ZCC code has zero cross correlation ($\lambda_c = 0$).

Generalized codes and ZCC codes are compared in terms of BER, No. of users and received power at different data rates. Numerical results are also obtained and compared.

SAC–OCDMA system is implemented using both codes (ZCC code & generalized code) and analyzed over FSO channel at different data rates and turbulence condition.

Contents

Chapter 1

Introduction

1.1. Introduction and Motivation

A communication system for multiple accesses is a communication network where many users share a common media for transferring data to a number of locations. Another primary issue required to be resolved in changing the communication system from a single user to a multi-user system is how the available transmission media can be efficiently divided between all customers.

The OCDMA system has been recognized as a main technique for supporting many customers in shared media simultaneously. Each user is assigned different codes and all users can use the same asynchronous and simultaneous medium.

Multiple Access Interference (MAI) impacts the OCDMA system, reducing the signal to noise ratio of the system.
There are many methods to lower the MAI in OCDMA, but the most effective is the Spectral amplitude coding optical code division multi-access (SAC–OCDMA).

Using the ideal in-phase cross correlation characteristic of codes, multiple access interference is totally abolished in the SAC-OCDMA technique.

It is a cost-effective method as it utilizes incoherent light-emitting-diodes (LEDs) as sources for SAC encryption. These devices are also affected by phase-induced intensity noise (PIIN). PIIN occurs because of the incoherent light mixing and incident on photo detector. Because of blending two uncorrelated light fields with the same polarization, low frequency noise, same spectrum and intensity, PIIN is mainly caused. Low cross-correlation characteristics effectively reduce MAI and PIIN.
Thus developing code with low cross-correlation is the important characteristic with detection scheme [1-3].

Several coding techniques have been developed for the SAC-OCDMA [1-6, 14, 20].

In this thesis Generalized Code and the Zero Cross Correlation Code (ZCC) is studied and analyzed in terms of BER, No of users and FSO system is also implemented using these codes to analyse the performance of SAC–OCDMA system at different parameters of FSO channel.

1.2. Thesis Organisation

This thesis is divided into 8 chapters including introduction.

In first chapter, the introduction of the whole project work is given and second chapter gives the information about current research trends on Optical CDMA using Spectral amplitude coding. The objective of this project also described in this chapter.

In chapter 3, the optical CDMA and Spectral OCDMA is explained in detail. This chapter is again divided into two sub parts. First part deals with OCDMA technology classification, challenges & advantages of OCDMA. Second part deals with SAC–OCDMA basic structure of encoder & decoder design and different detection techniques are explained.

In chapter 4, the basic understating of free space communication is given. Different features and challenges of FSO are also described in this chapter.

In chapter 5 & 6, the generalized code & zero cross correlation (ZCC) codes have been studied in detail respectively. It deals with Code construction (Gen. Code & ZCC Code) and numerical analysis along with FSO channel implementation for both codes.

In last the chapter 7 deals with results & discussion part. In this chapter all numerical and simulation results are given with comments.

Finally, thesis is concluded in chapter 8.

Chapter 2

Literature Survey

2.1. Current Research in OCDMA

The potential requirement for telecommunications services goes forward day after day not only to faster and more effective but also to strong safety.
Due to its unlimited bandwidth capacity, the optical network is an efficient solution for many services but the optical fiber deployment at all location is very difficult and costly.

Therefore researchers are interested into finding the solution for high speed network for all difficult locations where fiber deployment is not possible or costly. Optical network can be used in conjunction with other technology, this type of hybrid technology can provide high speed network.
Hybrid network such as optical network with FSO channel using OCDMA codes.

Many research papers on hybrid network have been studied [8-10 11, 14], some of are given below:
Hybrid network review: OCDMA and WDM [8], BER analysis of optical space shift keying in atmospheric turbulence environment [9], Performance of SAC–OCDMA –FSO communication systems using Khazani–Syed (KS) codes [14]. Hybrid WDM and Optical CDMA over waveguide grating based fiber to home networks [10]. Effect of different codes on a W–band WDM–over–OCDMA system [11]

In literature survey, it is found that Optical CDMA is using different coding techniques gives promising solution but OCDMA system primarily affected by multiple access interference (MAI) and cross-code correlation [1-5, 7,12, 19-20]. Spectral Amplitude Coding–OCDMA technique addresses the Multi-Access Interference Problem (MAI), but these schemes are still influenced by Phase Induced Intensity Noise (PIIN). This issue occurs because of incoherent light blending.
The SAC OCDMA system has been improved through a wide variety of coding systems: Modified quadratic prime weight congruence code [19], extended perfect difference code family for limited weights, multi-service code design for fixed-weight code in a basic matrix with a variable number of customers and mapping to obtain codes for an increasing number of users. Double weight code is designed for weight 2 only.
MDW(Modified double weight) code [19] & EDW (Enhanced double weight code) [7], Khazani – Syed (KS) code [14] and many others.
A generalized algorithm for code construction is reported in [1]. Which can generate

codes (Generalized codes) like EDW and MDW for any weight greater than 2 without mapping. It maintain cross correlation value almost one ($\lambda_c \leq 1$).
Zero cross correlation code can be generated [3-5] for any weight with zero cross correlation (λ_c=0).

2.2. Objective

The aim of this project is to use Generalized Code and ZCC Code to evaluate the efficiency of the SAC-OCDMA System in terms of BER, Maximum No of users and received power at varying data rates.

Analyze the performance ZCC codes and Generalized codes in free space (FSO) communication channel at different data rates and turbulence condition.

Chapter 3

Optical Code Division Multiple Access (OCDMA)

3.1. Introduction to Optical CDMA

A more versatile optical technology will be needed in the future. The Optical code division multiplexing (OCDM) is highly regarded as one of the applicants. OCDMA was complex and impractical in earliest generation relying on a direct transformation from the electrical to the optical domain. However the development of the Optical spectral Amplitude coding (OSAC) scheme has revived the viability of this technology with a simpler approach.

The nature of OCDMA for the safety of enterprise and military networks was concerned. In this area, many previous researches concentrate on simple OCDMA technologies and their applications on optical coding. Here the developments in the OCDMA and WDM / FSO combination systems also studied such as type of OCDMA coding, safety and system performance.

Optical access techniques that are used for sharing the optical network medium between simultaneous users are: time division multiple access (TDMA), wavelength division multiple access (WDMA) and code division multiple access (CDMA). The WDMA & TDMA used in Passive optical networks (PONs) but there techniques have re-synchronization problem and require expensive optical components.

Systems operating through WDM assign a distinctive wavelength from a set of available wavelengths. On the other side, each customer in OCDMA has a distinctive code (set of wavelengths) as an authorization password that extends across a comparatively broad bandwidth. It modulates the particular code, and then arbitrarily sends a message signal to the expected recipient that can correspond with the right code to retrieve the encrypted data.

The spectrum of information signals is extended as a spectrum designation when OCDMA coding is carried out. Many chips in code sequences are allocated for each customer to share the same transmission line with power dividers or combiners. This can be done in the optical domain or also in the space domain. Decoders at the recipient recognize a target code by correlation of received signal with allocated code.

High auto-correlations of intended codes are essential, although unwanted codes generate cross-correlation with minimum power level. Cross-correlations are generally provided between two distinct codes. An outstanding code structure has a comparatively long code with a strong auto correlation for several customers.

The application of optical code division multiple access (OCDMA) into the local area network, OCDMA-PON and the free space optical network (OCDMA-FSO) is motivated by the ability to manage asynchronous traffic and no need of network management protocols.

In Figure 3.1 the Communication Network Block Diagram using Optical-CDMA technology is presented. This Optical CDMA is a transmission technique that transmits all data across the network.
When a receiver has a bar code that matches one of the transmitters on the network, that signal is decoded and extracted from the network.

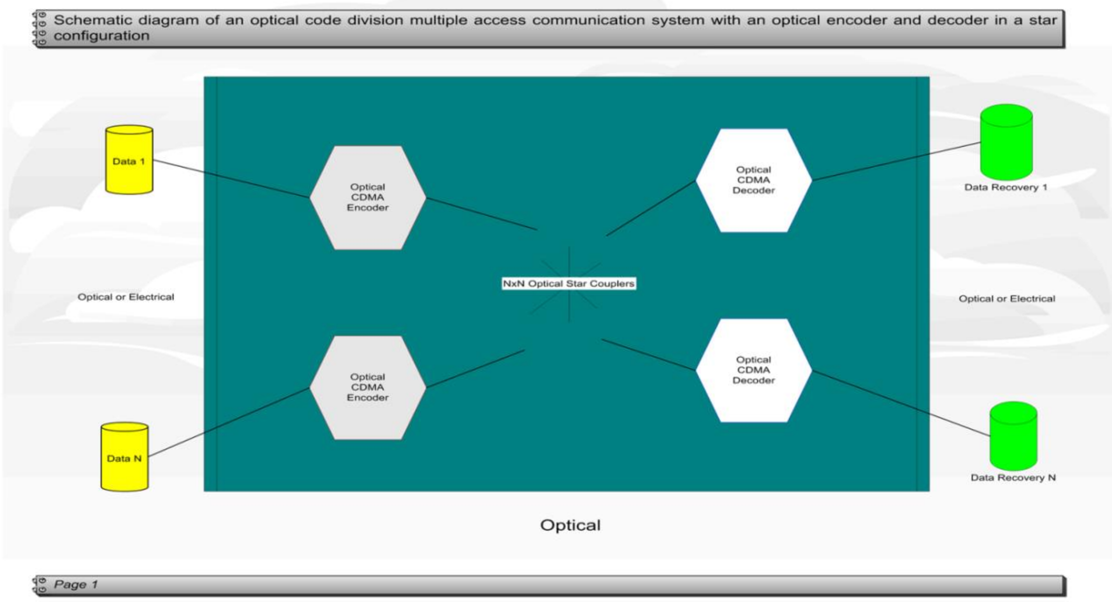

Fig. 3.1 Block diag. of Communication network using Optical-CDMA Technology [10]

3.1.1. Optical CDMA Classification

We can classify the Optical–CDMA in six categories as per coding approaches [8, 10-11, 13]:

1. Direct-sequence coding (DS–OCDMA)
2. Spread space coding (SSC–OCMDA)
3. Temporal phase coding (TPC–OCMDA)
4. Spectral Phase Coding (SPC–OCDMA)
5. Spectral Amplitude Coding (SAC–OCMDA)
6. Hybrid coding (HC–OCMDA)

In the DS–OCDMA the code sequence is multiplied by the user data signal. The sequence is mainly binary. An element's length in a code is known as the "chip time." The ratio of the user's symbol time to the chip time is known as the spreading factor.

In hybrid coding schemes, the combination of coding techniques listed above are used in one system such as wavelength hopping time spread coding technique (combination of spectrum and temporal coding). In this project the SAC–OCDMA technique is used because it does not have multiple access interference problems.

We can further divide the OCDMA system as per resources used in coding techniques as shown in figure 3.2.

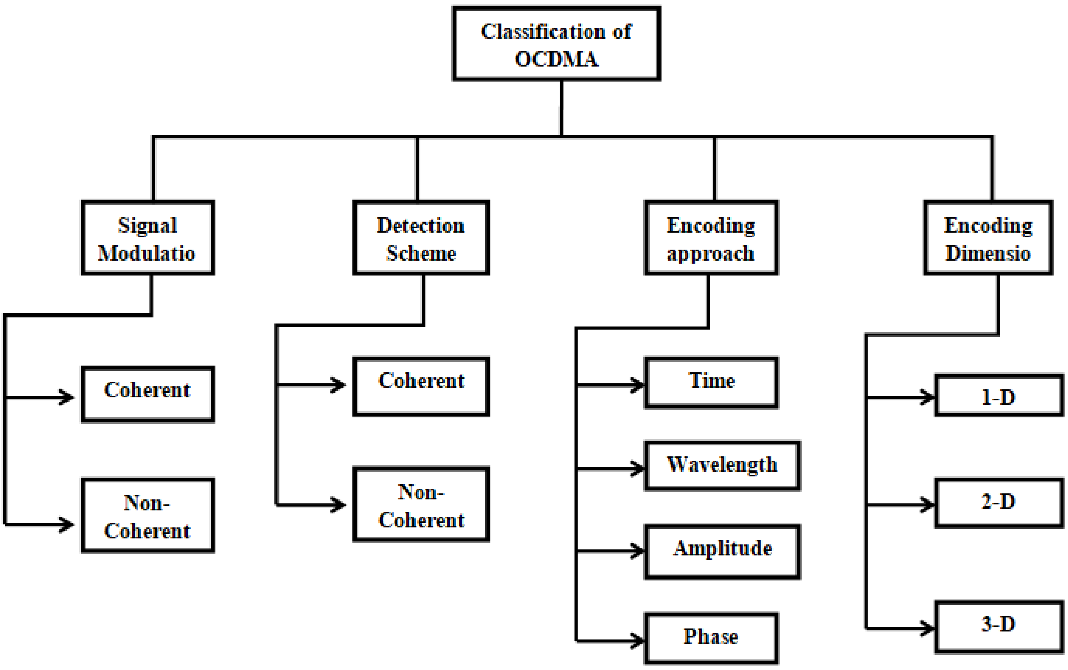

Fig. 3.2 Classification of Optical-CDMA Technology [8]

3.1.2. Advantages & Challenges of OCDMA

There are characteristics that render OCDMA system an appealing option for broadband services in the next generation. The OCDMA multiplexing concept enables for more number of channels than other methods, enables asynchronous communication with effective connectivity and effectively improves network data safety.

In addition, it uses simpler network monitoring and management as well as multi-class data with distinct sizes and data rates. Its design can be quickly reconfigured.

Simplified and affordable OCDMA systems can be deployed and generated depending on the use of incoherent sources.

In spite of these prospective benefits, this technology is challenged by certain problems. For example, multi-users interference produces beat noise which damages system performance, particularly when close wavelength optical pulses are transferred.

Moreover, for spectrally encrypted OCDMA, the currently available broadband light sources either have insufficient produced strength or the device is costly.

3.2. Spectral Amplitude Coding – OCDMA (SAC – OCDMA)

Various encryption methods for Optical CDMA have been evolved that are discussed in Chapter 3.1.1.

Multiple access interference (MAI) effect is the key problem with these coding techniques. The MAI introduced simultaneous transmission from other users. It is the primary consequence that reduces the system's efficient bit error rate (BER).

The Spectral Amplitude Coding (SAC) for Optical CDMA has been introduced to overcome the effect of MAI and maintain the cross correlation minimum as much possible as and high auto correlation.

SAC-OCDMA schemes provide the amplitude of the light spectrum for each network consumer with a distinctive spectral amplitude code word. It maintains the orthogonality in the system among the consumers.

The basic block diag. of the system (SAC-OCDMA) is shown in Figure.3.2. It consist a transmitter section for each user. Each user transmitter section consist of a light source (LED), encoder, user data and modulator. The each user output is combined, encoded and transmitted to Communication channel. The received signal is split & decoded at receiver end. The received signal after decoding is sent to detector of each user.

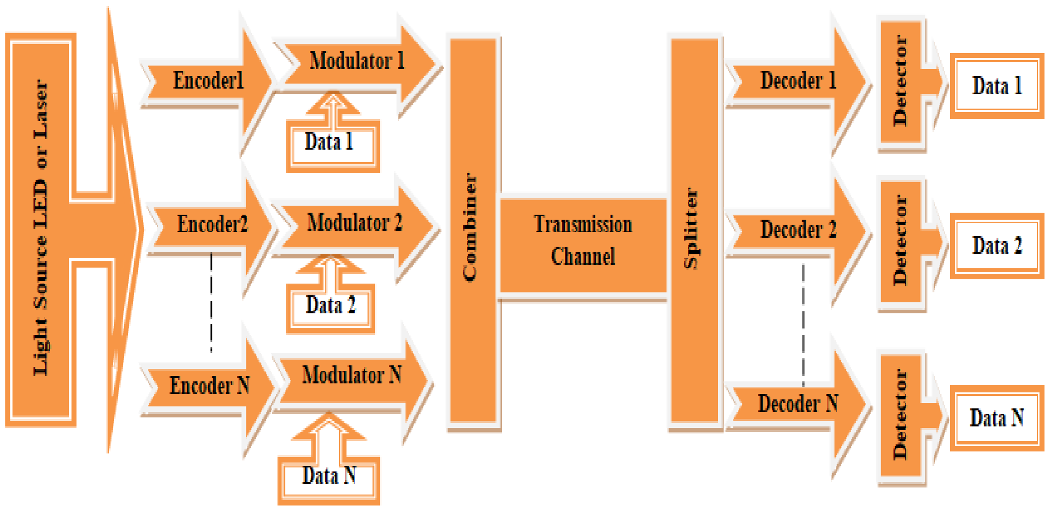

Fig. 3.3 Block diag. of SAC-OCDMA System

At Transmitter part, the source should be a broadband light source with high spectral power density, which makes LED as a good candidate to be used.

The code will be encoded using an external modulator and ready to transmit through the communication channel.

In the figure 3.3 it is shown that each user has its encoder and decoder. The design of encoder and decoder is depended on the coding technique. Encoder and decoder design must be simple and easy to implement. By using proper coding technique the system cost and complexity can be reduced.

3.2.1. Direct Detection Technique

At the receiver side the detector is used for each user.
There are many detection techniques have been developed among them Direct Detection technique give better performance. In the direct detection only unique wavelength for particular user is detected. Therefore the system complexity and cost reduces.

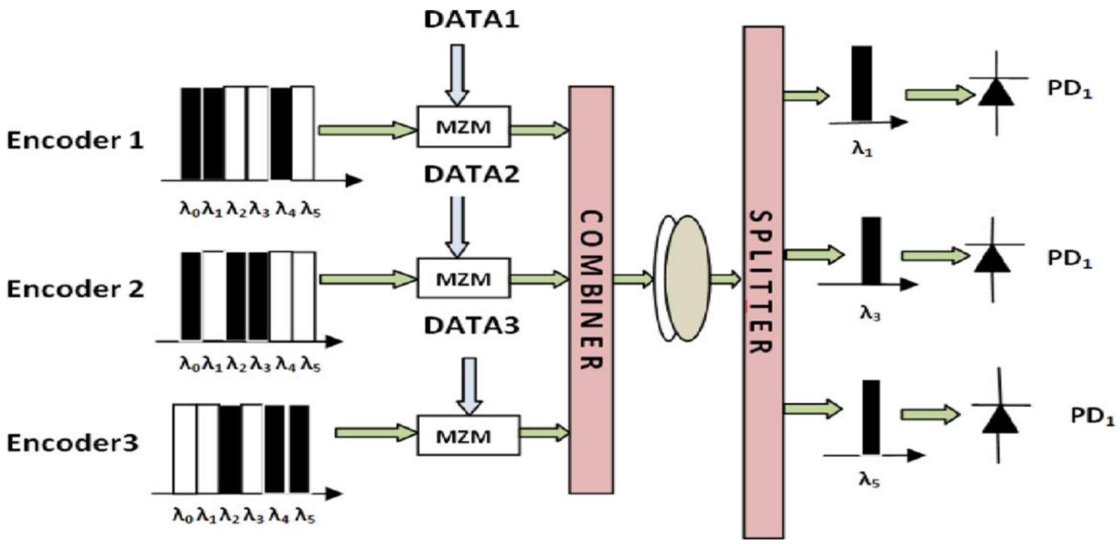

Fig. 3.4 Block diag. of SAC-OCDMA System using Direct Detection Technique [1-2, 7]

Figure 3.4 shows the SAC– OCDMA system using direct detection (DD) technique.

Here generalized code (*ch.5*) for W=3, N=3 is used to understand the encoding and decoding process for SAC–OCDMA System.

In decoding of generalized code the non-overlapping wavelengths are selected and sent to photo diode. These wavelengths that do not overlap are specific to each consumer. For detecting wavelengths in direct detection, one photo detector is necessary as shown in figure 3.4.

- **The generalized code matrix is indicated below (W=3, N=3):**

$$
Code = \begin{array}{r} Wavelengths \rightarrow \\ User1 \rightarrow \\ User2 \rightarrow \\ User3 \rightarrow \\ Sum \rightarrow \end{array}
\begin{array}{c} \overbrace{\lambda_0 \;\; \lambda_1 \;\; \lambda_2 \;\; \lambda_3 \;\; \lambda_4 \;\; \lambda_5} \\ \begin{bmatrix} 1 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 \end{bmatrix} \\ \underbrace{0 \;\; 1 \;\; 0 \;\; 1 \;\; 0 \;\; 1} \end{array} \qquad (3.1)
$$

This matrix gives three unique codes for three users. For each user three wavelengths (corresponding to one's in unique code) are selected and transmitted as shown in figure 2.

(User 1= $\lambda_{0,}$ λ_1 & $\lambda_{4,}$ User 2 = $\lambda_{0,}$ λ_2 & $\lambda_{3,}$ and User 3 = $\lambda_{2,}$ λ_4 & λ_5)

Each user has one i.e. (W–2) non- overlapping wavelength. These wavelengths are corresponding to one's in sum in equation (3.1).

- **Non-overlapping wavelengths are as follows:**

λ_1 = user1, λ_3 = user2 and λ_5 = user3

In the direct detection these three non-overlapping wavelengths are used.

At the receiver side these wavelength will be detected as shown in figure 4.4.

3.2.2. Balanced Detection Technique

The received signal is divided into two branches for balanced detection. The decoder's top branch utilizes the same wavelength architecture as the corresponding encoder. The wavelength architecture in the decoder's lower branch is designed by the binary sum in equation (3.1).

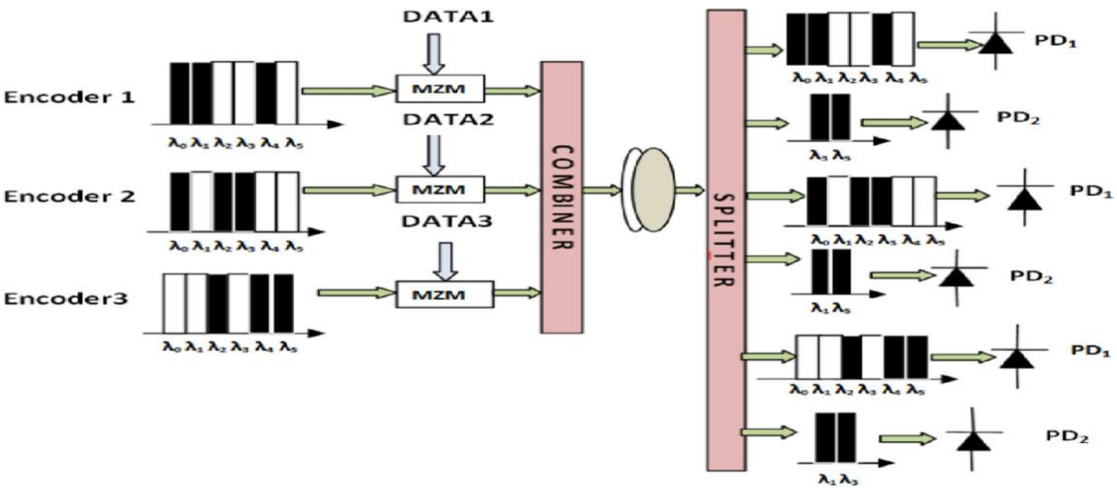

Fig.3.5 SAC-OCDMA system block diagram using a balanced detection method. [1]

Figure 3.5 shows the SAC– OCDMA system using balanced detection technique. Here also generalized code for W=3, N=3 is used for encoding and decoding purpose.

From equation (3.1), there are three users and each user has a unique code. There are (W–2) i.e. One non overlapping wavelength for each user.

At the transmitter side for each user wavelengths are selected as per corresponding unique code.

At the receiver side decoder has two parts as shown in figure 3.5 Upper part of decoder contains the same wavelengths as selected in encoder.

The lower part of decoder contains non overlapping wavelengths except non – overlapping wavelength of respective user. The signal of both parts of decoder will be forwarded to photo diode of corresponding decoder part and resultant signal will be forwarded to low pass filter for further processing.

In figure 3.5 the upper part of each user decoder contains following wavelengths:

Upper part of decoder 1 = User 1= $\lambda_{0,}$ λ_1 & λ_4,
Upper part of decoder 2 = User 2= $\lambda_{0,}$ λ_2 & λ_3,
Upper part of decoder 3 = User 3= $\lambda_{2,}$ λ_4 & λ_5,

Similarly lower part of each decoder contains following wavelengths as shown in figure 3.5:

Lower part of decoder 1 = User 1= λ_3 & λ_5,
Lower part of decoder 2 = User 2= λ_1 & λ_5,
Lower part of decoder 3 = User 3= λ_1 & λ_3,

Chapter 4

Free Space Optical Communication

An overview of Free Space Optical (FSO) technology along with the advantages, limitations and applications is presented in this chapter.

4.1. Introduction to Free Space Optical Communication System (FSO)

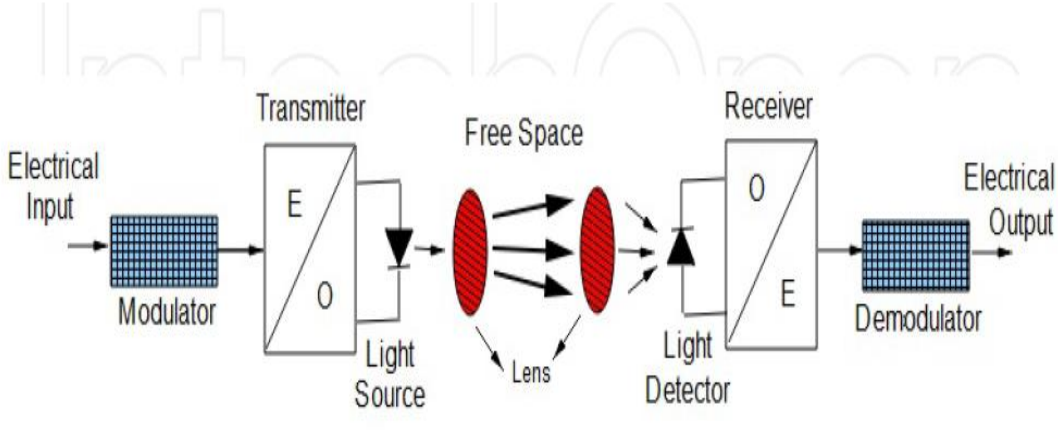

Fig. 4.1. General block diagram of FSO Communication System [9]

FSO is a technique of optical communication that propagates signal in open space implies atmosphere, vacuum, Space outdoors or kind of comparable to wireless transmission of information for telecommunications and computer networking.

It is a line of sight (LOS) technique which utilizes LED or laser as a source for optical link. Compared to traditional RF communication, FSO has tremendous benefits. In the Free space optical link comparative to the Radio Frequencies, very large optical range is available, which allows increased data rates.

FSO also doesn't include fiber excavation and landowner’s permission. It is possible to make installation faster. Compared with fiber optic communication, cost is lower. The FSO equipments are handy, compact and simple to exchange.

Figure 4.1 presents the fundamental diagram of FSO system. In FSO, there are three primary operational components: transmitter, atmospheric channel and receiver.
The modulator modulates the transmitter data stream and converts the electric signal to an optical signal by means of an optical source (LED or laser). LED or laser radiation is matched to the receiver through a lens with a collimated beam.

The signal is transmitted through the air and is attenuated owing to scattering, absorption and turbulence. The signal is degraded because of harsh climate conditions such as snow, rain, haze, fog and turbulence. On the receiver hand, the telescope or lens receives the incoming radiated wave and transfers to optical filter. The optical filter permits only required wavelengths to cross and prevents other atmospheric radiation.

The sensor converts optical signal to electrical signal and deliver the signal to amplifier. The information is recovered by the decision device and the clock recovery system at the end of the receiver handling module.

4.2. Optical Sources and Detectors

Wavelength choice is a significant parameter in FSO as it impacts the system's link efficiency and sensitivity of the detector.

FSO communication devices are primarily intended to function in the range of 780-850 nm and 1520-1600 nm applications.
At 850 nm, the Vertical cavity surface emitting laser (VCSEL) is accessible and a extremely delicate silicon Avalanche photodiode (APD) is also accessible.

Lasers like Distributed Feedback (DFB) lasers and Febry Perot (FP) lasers with a greater power density of up to 100 mW / cm^2 are suitable for the wavelength range from 1300 nm to 1550 nm [9, 21].

The spectrum of 1550 nm is attractive as the sunlight background / scattering decreases and it is also compatible with WDM (wavelength division multiplexing) systems. Using wavelengths range 1520 nm to 1600 nm power can be enhanced approximately 50–65 times more relative to range 780 nm to 850 nm.

For longer wavelength range the InGaAs material is mainly used as detector material in most of the optical communication system.

For transmission in fog, higher wavelengths are suitable as higher wavelengths are less affected by fog. Light Emitting Diode (LEDs) are accessible at the near infrared range, which are non-coherent light source. LED's are lower in cost and need a simpler driver circuit.

4.3. Advantages of FSO System

There are several advantages of FSO System listed below:

- Higher Data Rate:

  Free space optics is versatile network with a higher speed It can achieve 10 Gbps data rates.

- Electromagnetic interference immunity:
  The transmission in FSO link cannot be affected by electromagnetic and radio-magnetic interference.
- Long-range operation without a license:
  There is no need for customer spectrum permit as needed in radio and microwave devices
- Protocol transparency: There is no need of protocol management.
- Invisible and eye safe.
- Fast and easy deployment of FSO devices.
- No Fresnel zone necessary.
- Low cost maintenance.

4.4. Limitations of FSO system

It is simple to catch up with the benefits of free space optics. However, as the transmission medium is air for FSO and the light is passing through it, some environmental challenges are inevitable. Troposphere regions are the most frequent region of the atmospheric phenomenon. Figure 4.2 shows the impact of these atmospheric constraints.

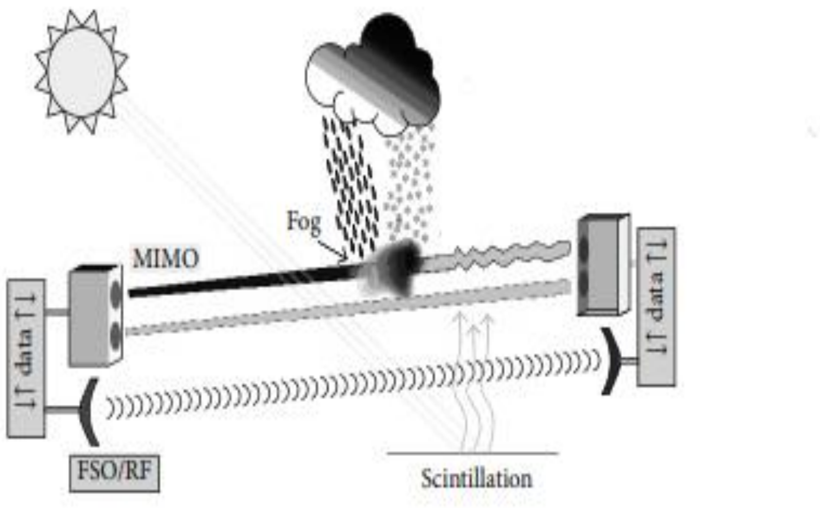

Fig. 4.2. Impact of atmospheric constraints on FSO Communication System [9]

Some of these limitations are outlined below briefly:

- **Geometric losses:**

These losses occur due to misalignment of transmitter and receiver. Geometric losses that can be called optical beam attenuation are caused by the spread of the beam and low power of the signal as it travels from transmitting to receiving end.

- **Scintillation:**

Different wind bubbles would have temperature differences due to the heat increasing from the ground and man-made devices such as cooling ducts. These variations in temperature may cause fluctuations in the amplitude of the signal at the receiving end of the FSO causing "image jumping."

- **Scattering:**

When the beam and scatterer collapse, scattering events occur. It is a phenomenon dependent on the wavelength that does not change optical beam power. However, only directional redeployment of the optical energy results in the beam intensity reduction over a long distance.

- **Physical impediments:**

Floating birds, mountains, and high rise buildings may completely prevent an optical beam, whenever these appear in between FSO transmission.

- **Absorption:**

Water molecules floating in the terrestrial atmosphere cause absorption. These particles would absorb the photon energy. The optical beam power density is reduced, and absorption immediately affects the accessibility of the transmission in the FSO system. Carbon dioxide may also lead to signal absorption.

- **Atmospheric turbulence:**

The climate and environmental composition cause atmospheric turbulence. Wind and convection cause the water bubbles to mix at various temperatures. The air density fluctuates as a result, and the air refractive index change.

- **Atmospheric attenuation:**

Fog and haze normally result in atmospheric attenuation. Dust and rain are also a factor. Atmospheric attenuation is supposed to depend on wavelength. But this isn't accurate. The haze weather depends on wavelength however it offers lower attenuation at 1550 nm. The attenuation in the conditions of fog is independent of the wavelength.

4.5. Applications of FSO system

Currently, in many fields, the FSO communication channel is used for many facilities. Some of these are as follow:

- **Wireless outside connectivity**:

It can be used for wireless communication for example, point-to-point connections, between buildings, ships and point-to-multi-point connections for short and long-range communication, satellite to ground. It doesn't require a permit as needed for microwave channels.

- **Storage Area Network (SAN):**

For SAN formation, FSO system can be utilized. It is a network renowned for providing access to centralized information storage at block level.

- **Last Mile Connection:**

For high speed connection at last mile, laying and digging of fibre cable is very expensive therefore FSO system can be used with other networks (fibre network) in the last mile to fix this issue.

- **Military Use:**

As this technology is easy to install and safe system, therefore it is useful in military operations. Its increased data rates and low cost makes it more suitable for this purpose.

Chapter 5

SAC – OCDMA System using Generalized Code

5.1. Generalized Code:

5.1.1. Code Construction

- **The Generalized code development algorithm for SAC–OCDMA scheme is specified below** [1, 3-6]**:**

  - Choose W (weight of code), N (no of users),
  - Calculate L (code length) using L= N × (W–1)
  - Develop Base Matrix M as per equation (1).
  - Repeat base matrix (M) up to (N – 1) times.
  - In last column of Matrix C, R1 is placed at last row and R2 is placed at first row as per equation (5.2).
  - Fill empty places with zeros.

- **Basic Matrix (*M*) is constructed as follows:**

$$M = \begin{bmatrix} R_1 \\ R_2 \end{bmatrix} = \begin{bmatrix} \left\lfloor \frac{W-2}{2} \right\rfloor 0s & \left\lfloor \frac{W+1}{2} \right\rfloor 1s \\ \left\lfloor \frac{W}{2} \right\rfloor 1s & \left\lfloor \frac{W-1}{2} \right\rfloor 0s \end{bmatrix}_{2\times(W-1)} \tag{5.1}$$

- **The Code is constructed as follows:**

$$C = \begin{bmatrix} R_1 & 0 & 0 & \cdots & \cdots & \cdots & R_2 \\ R_2 & R_1 & 0 & \cdots & \cdots & \cdots & 0 \\ 0 & R_2 & 0 & \cdots & \cdots & \cdots & \vdots \\ \vdots & \vdots & \vdots & \ddots & \ddots & \ddots & \vdots \\ \vdots & \vdots & \vdots & \ddots & \ddots & R_1 & 0 \\ 0 & 0 & 0 & \cdots & \cdots & R_2 & R_1 \end{bmatrix}_{N\times L} \tag{5.2}$$

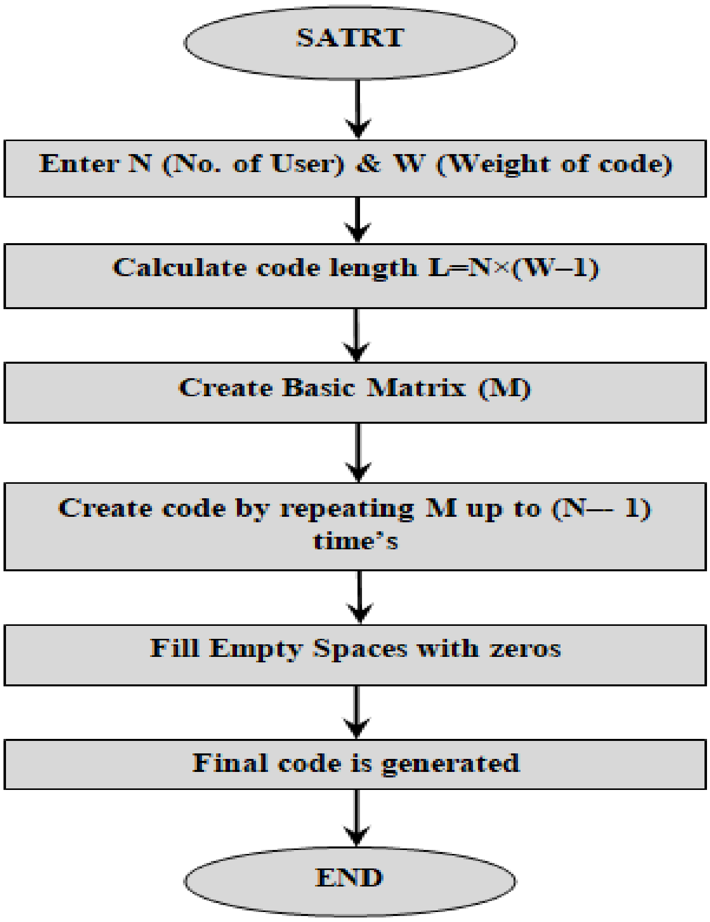

Fig. 5. 1. Generalized code construction algorithm [1]

5.1.2. Code construction examples

➢ **The generalized code for W=3, N=3 is given in equation (5.4)**

Basic matrix (*M*)

$$M = \begin{bmatrix} 1 & 1 \\ 1 & 0 \end{bmatrix}_{2\times(W-1)} \quad (5.3)$$

Code (C)

$$C = \begin{bmatrix} 1 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 \end{bmatrix}_{N\times L} \quad (5.4)$$

➢ **The generalized code for W=4, N=3 is given in equation (5.6)**

Basic matrix (*M*)

$$M = \begin{bmatrix} 0 & 1 & 1 \\ 1 & 1 & 0 \end{bmatrix}_{2\times(W-1)} \quad (5.5)$$

Code (C)

$$C = \begin{bmatrix} 0 & 1 & 1 & 0 & 0 & 0 & 1 & 1 & 0 \\ 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 \end{bmatrix}_{N\times L} \quad (5.6)$$

➢ **The generalized code for W=4, N=5 and L=15**

$$C = \begin{bmatrix} 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \\ 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 \end{bmatrix}_{N\times L} \quad (5.7)$$

5.2. Generalized code performance analysis

Let C_x(j) is the *j*th element of the *k*th code sequence. The (W–2) wavelengths (Not overlapping with others) are chosen for each consumer by product of Cz(j) and the desired consumer.

➢ **Function of correlation is presented as follows** [1]**:**

$$C_x(j) = \sum_{j-1}^{L} (C_z(j).C_k(j)) \quad (5.8)$$

$$= \begin{cases} W-2 & k = l \quad same\ user \\ 0 & k \neq l \quad other\ users \end{cases} \quad (5.9)$$

➢ To Calculate the System BER performance, the Gaussian approximation is used [1, 7]:

- All the light sources are ideally unpolarized & its spectrum is flat for given bandwidth [v0-Δv/2, v0+Δv/2], where v0= central optical frequency and Δv = source bandwidth.
- For all users each bit stream is synchronized.
- For all users received power is equal.
- Each frequency component has the same spectral width.

➢ **SNR for Generalized code using Direct Detection Technique** [1]**:**

$$SNR = \frac{\left(\frac{RP_{sr}W}{L}\right)^2}{\frac{eBRP_{sr}(W-2)}{L} + \frac{4k_b T_n B}{R_L}} \tag{5.10}$$

Where:

$$R = responsivity = \frac{\eta e}{(h\nu_0)}, \tag{5.11}$$

$\eta =$ Quantum efficiency

$h\upsilon_0 =$ Photon energy, $e =$ Electron charge

B= Receiver Electrical Bandwidth, $k_b =$ Boltzmann's constant

T_n = Absolute temperature, R_L=Receiver load resistor

L= Length of code, W= Weight of code,

P_{sr} = Effective received power

➢ **BER for Generalized code using Direct Detection Technique** [1,3-5]**:**

$$BER = \frac{1}{2} erfc\sqrt{(SNR/8)} \tag{5.12}$$

5.3. SAC–OCDMA System using Generalized Code over FSO Channel:

To analyze the performance of generalized code in FSO channel, Optisystem simulation software is used. Snapshot of simulation setup for SAC-OCDMA (W=4, N=5) is shown in figure 5.2.
This system is implemented for five users (N=5) with code weight W=4.

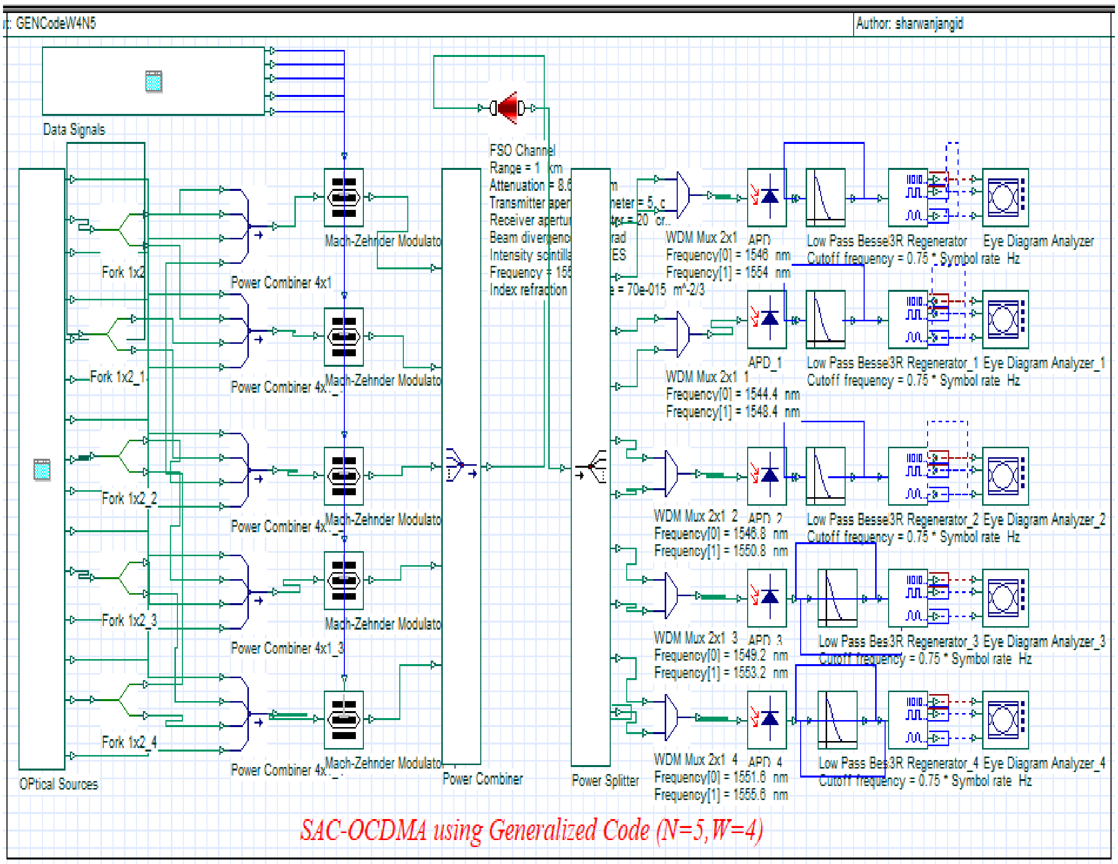

Fig. 5. 2. Snapshot of simulation setup for Generalized Code

The Generalized code for N =5 & W=4 is given in equation (5.7). The code length (L) is 15 therefore 15 wavelengths are required. These wavelengths and FSO channel parameters are listed in table 5.1.

This system is analyzed under turbulence condition at 622 Mbps and 1.5 Gbps for 0.1 to 1 Km FSO range.

Table 5.1 Parameters used in Simulation [1-2, 12**]:**

Parameter	Value
LED output power (Each source)	10 dBm
Quantum Efficiency	0.6
Line width	3.75 THz
FSO Range	0.1 to 1 km
Atmospheric Attenuation	8.68 dB/km
Transmitter Aperture diameter	5 cm
Receiver Aperture diameter	20 cm
Beam Divergence	1 mrad
Intensity Scintillation	Yes
Frequency	1550 nm
Index Refraction structure	7e-14 (lower turbulence)
APD Gain	10
Responsivity	1 A/W
Ionization ration	0.9
Dark Current	5 nA
Thermal Noise	100e-24 W/Hz
Short noise	Yes
Wavelength separation	0.8 nm
Wavelengths used for coding	1544.40 to 1555.60, 15 wavelengths @ 0.8 nm separation
Bit rate	622 Mbps, 1.5 Gbps

Chapter 6

SAC – OCDMA System using Zero Cross Correlation (ZCC) Code

6.1. ZCC Code:

6.1.1. Code Construction

The ZCC code construction for SAC–OCDMA system is stated below:

➢ **General form of ZCC code is as follows** [3,4,5]**:**

$$ZCC_{W=i} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \tag{6.1}$$

Where

$[A]=$ Matrix of pervious weight i.e. copy of ZCC_{W-1}.

$[B]=$(W×2W) Matrix, combination of diagonal matrix of ones with alternate of zeros matrix (W×1) in between

$[C]=$Matrix of zeros (1×W (W–1))

$[D]=$Repetition of matrix $[0\ 1]_{1\times 2}$ for W times and
i= integer {1,2,3…..}

➢ **Basic parameters for ZCC code is given below:**

Basic no of user

$$N_B = W+1 \tag{6.2}$$

Code length

$$L=W\,(W+1) \tag{6.3}$$

➢ **Code Mapping** [3-6]**:**

This technique used to increase the No. of users (codes) keeping weight (W) constant. The mapping technique process for ZCC code is given below:

$$Z_m = \begin{bmatrix} 0 & Z_{m-1} \\ Z_{m-1} & 0 \end{bmatrix} \qquad (6.4)$$

From eq. no (6.4) it is clear that as no. of user increases, the code length L also increases but weight (W) of code is remain same.

- **Code parameters with mapping process is given below:**

Mapped no of user (Nm)

$$Nm = 2^m (N_B) \qquad (6.5)$$

where:
'm' denotes how many times mapping process is repeated.

Mapped code length (L_m)

$$Lm = 2^m (L) \qquad (6.6)$$

6.1.2. ZCC code construction examples

- **ZCC code for W=1**

$$ZCC_{W=1} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \qquad (6.7)$$

- **ZCC code for W=2, mapping (m) = 0 and K_B = 3, L=6**

$$ZCC_{W=2,m=0} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 \end{bmatrix}_{K_B \times L} \qquad (6.8)$$

- **ZCC code for W=2, mapping (m) =1 and K_m = 6, L_m=12**

$$ZCC_{W=2,m=1} = \begin{bmatrix} 0 & Z_{m-1} \\ Z_{m-1} & 0 \end{bmatrix} = \begin{bmatrix} 0&0&0&0&0&0&1&0&1&0&0&0 \\ 0&0&0&0&0&0&0&1&0&0&1&0 \\ 0&0&0&0&0&0&0&0&0&1&0&1 \\ 1&0&1&0&0&0&0&0&0&0&0&0 \\ 0&1&0&0&1&0&0&0&0&0&0&0 \\ 0&0&0&1&0&1&0&0&0&0&0&0 \end{bmatrix}_{K_m \times L_m} \quad (6.9)$$

- **ZCC code for W=3, mapping (m) = 0 and K_B = 4, L=12**

$$ZCC_{W=3,m=0} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1&0&1&0&0&0&1&0&0&0&0&0 \\ 0&1&0&0&1&0&0&0&1&0&0&0 \\ 0&0&0&1&0&1&0&0&0&0&1&0 \\ 0&0&0&0&0&0&0&1&0&1&0&1 \end{bmatrix}_{K_B \times L} \quad (6.10)$$

- **ZCC code for W=4, mapping (m) = 0 and K_B = 5, L=20**

$$ZCC_{W=4,m=0} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}$$

$$= \begin{bmatrix} 1&0&1&0&0&0&1&0&0&0&0&0&1&0&0&0&0&0&0&0 \\ 0&1&0&0&1&0&0&0&1&0&0&0&0&0&1&0&0&0&0&0 \\ 0&0&0&1&0&1&0&0&0&0&1&0&0&0&0&0&1&0&0&0 \\ 0&0&0&0&0&0&0&1&0&1&0&1&0&0&0&0&0&0&1&0 \\ 0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&1&0&1&0&1 \end{bmatrix}_{K_B \times L} \quad (6.11)$$

6.2. ZCC code performance analysis

Let C_m and C_n are two ZCC code sequence with weight W.

- **Correlation function for ZCC is given as [3-6]**

$$\sum_{j-1}^{N} (C_m(j).C_n(j)) \quad (6.12)$$

$$= \begin{cases} W & m = n \quad Auto\ correlation \\ 0 & m \neq n \quad Cross\ correlation \end{cases} \quad (6.13)$$

- **SNR & BER calculation for ZCC**

Assuming bit synchronism and equal power at the receiver SNR & BER equation for direct detection can be written as [1, 3-6, 20]:

$$SNR = \frac{\left(\frac{RP_{sr}W}{L}\right)^2}{\underbrace{2eBR\left(\frac{P_{sr}W}{L}\right)}_{shot-noise} + \underbrace{\frac{4k_bT_nB}{R_L}}_{thermal-noise}} \tag{6.14}$$

Where:

$$R = responsivity = \frac{\eta e}{(h\nu_0)}, \tag{6.15}$$

$\eta =$ Quantum efficiency

$h\upsilon_0 =$ Photon energy

$e =$ Electron charge

B= Receiver Electrical Bandwidth

$k_b =$ Boltzmann's constant

T_n = Absolute temperature

R_L=Receiver load resistor

L= Length of code

W= Weight of code

P_{sr} = Effective received power

$$BER = \frac{1}{2} erfc\sqrt{(SNR/8)} \tag{6.16}$$

6.3. SAC–OCDMA System using ZCC Code over FSO Channel:

To analyze the performance of ZCC code in FSO channel, Optisystem simulation software is used. Snapshot of simulation setup for SAC-OCDMA (W=4, N=5) using ZCC code is shown in figure 6.1.
This system is implemented for five users (N=5) with code weight W=4.

The ZCC code for N =5 & W=4 is given in equation (6.11). The code length (L) is 20 therefore 20 wavelengths are required.

Twenty wavelengths from 1542.80 to 1558.00 at 0.8 nm separation is used in simulation. Other simulation parameters and FSO channel parameters are kept similar to generalized code. These are given in table 5.1.

This system is analyzed under turbulence condition at 622 Mbps and 1.5 Gbps for 0.1 to 1 Km FSO range.

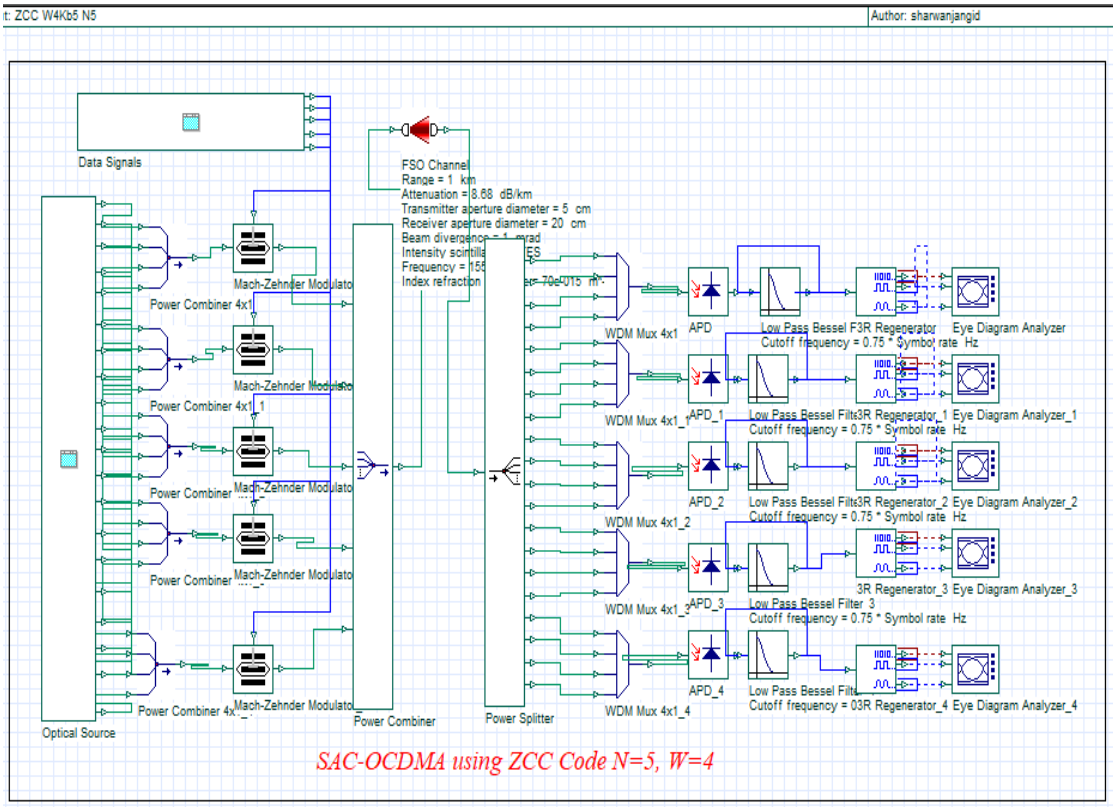

Fig. 6. 1. Snapshot of simulation setup for SAC-OCDMA using ZCC Code

Chapter 7

Results & Discussion

7.1. Code length comparison

Table 7.1 and Figure 7.1 shows the code length comparison between ZCC and Generalized code for different no of users at W=4.

In the SAC-OCDMA system it is desirable to have smaller code length. Code with smaller code length will require fewer components in encoding and decoding process. This makes the system cost effective and simple.

Here the ZCC code requires more code length than generalized code.

Table 7.1 Comparison of code length for ZCC and Generalized code

Sr. No.	Codes	Weight	No. of Users	Code – length	Cross – correlation
1.	ZCC Code	4	5	20	0
			10	40	
			20	80	
			30	120	
			40	160	
			50	200	
2.	Generalized Code	4	5	15	1
			10	30	
			20	60	
			30	90	
			40	120	
			50	150	

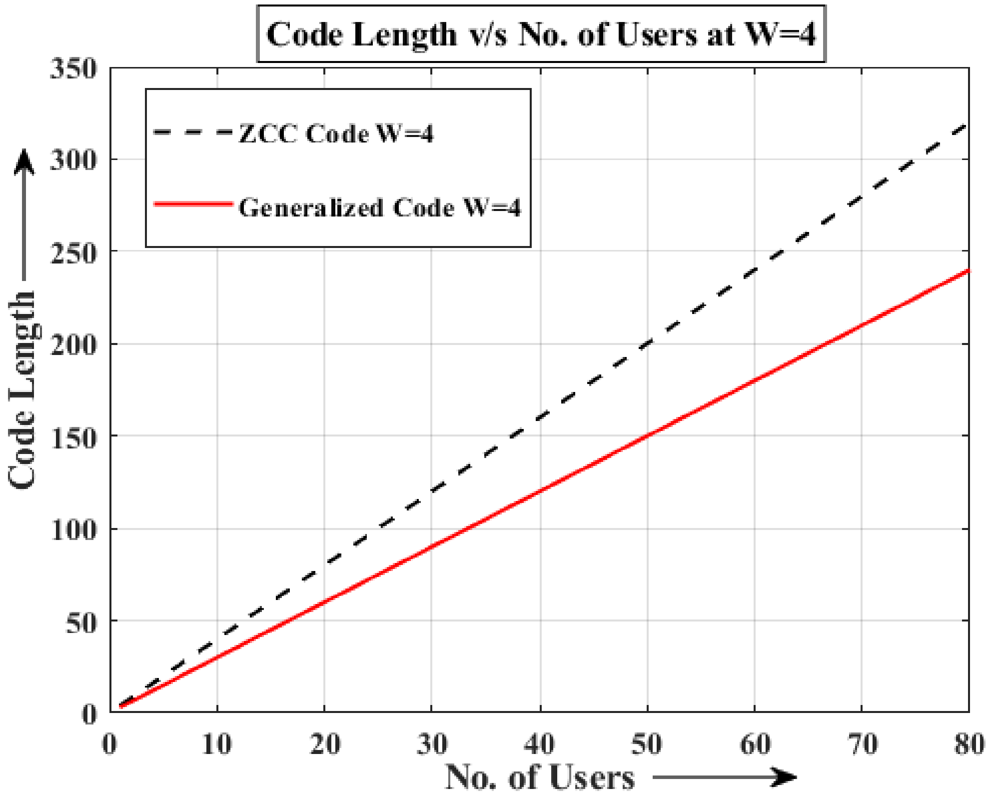

Fig. 7.1 Code length comparison

7.2. Numerical Results:

ZCC code and generalized code have been analysed by referring to the bit error rate (BER). Table 7.2 shows the general parameters used in numerical calculation.

Table 7.2 Parameter used for numerical calculation

Sr. No.	Parameters	Values
1.	Line width of broadband source ($\Delta\upsilon$)	3.75 THz
2.	Electrical bandwidth (B)	311 MHz
3.	Effective Received Power (P_{sr})	–10 dBm
4.	Quantum Efficiency (η)	0.6
5.	Operating wavelength (λ_0)	1550 nm
6.	Receiver noise temperature (T_n)	300 K
7.	Receiver load resistor (R_L)	1030 Ω
8.	Electron charge (e)	1.6×10^{-19} C
9.	Planck's constant (h)	6.66×10^{-34} J/S
10.	Boltzmann's constant (k_b)	1.38×10^{-23} J/K
11.	Data rates	0.622, 1.5, 2.5 and 5 Gbps

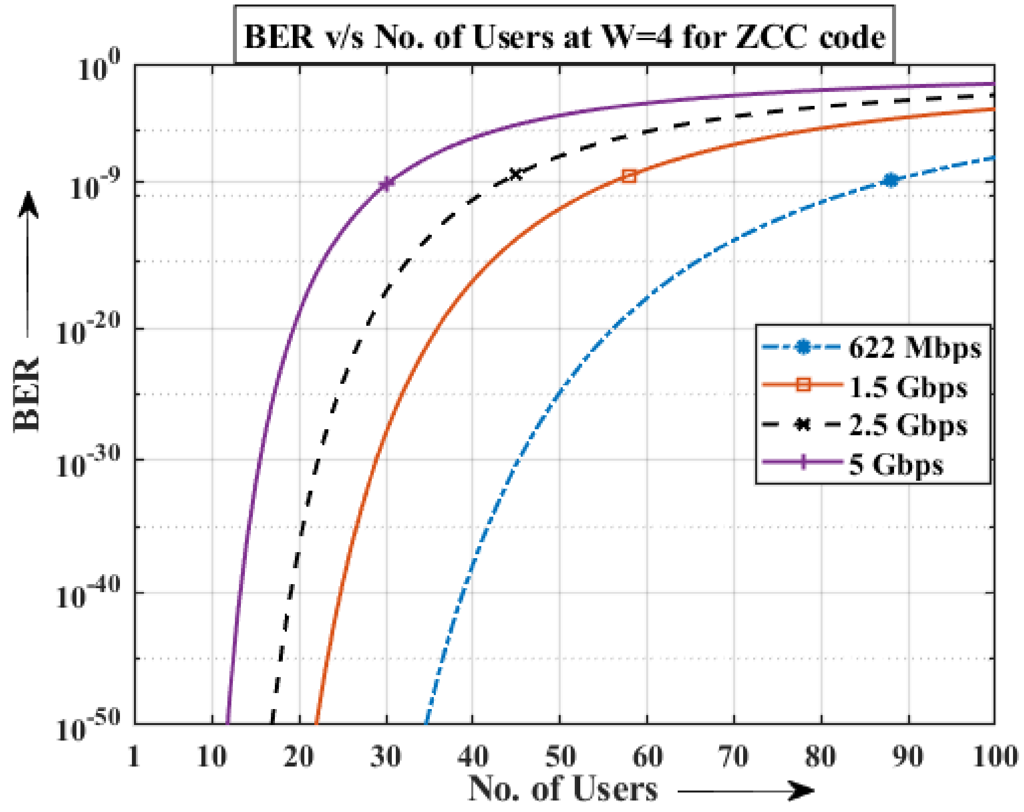

Fig. 7.2 BER versus No. of users for ZCC Code

The figure 7.2 shows the comparison between BER versus active users at different data rates for ZCC code based on equation (6.14) and (6.16).

The BER of the system increases at higher data rates for the same active no of users. At higher data rates required bandwidth increase, therefore noise in the system increases. Thus the system performance degrades at higher data rates.

This graph is obtained for ZCC Code W=4 and Psr = –10dBm. From this graph, the ZCC code can accommodate 88, 58, 45, & 31 users with acceptable BER ($<10^{-9}$) at 0.622, 1.5, 2.5 & 5 Gbps data rates respectively.

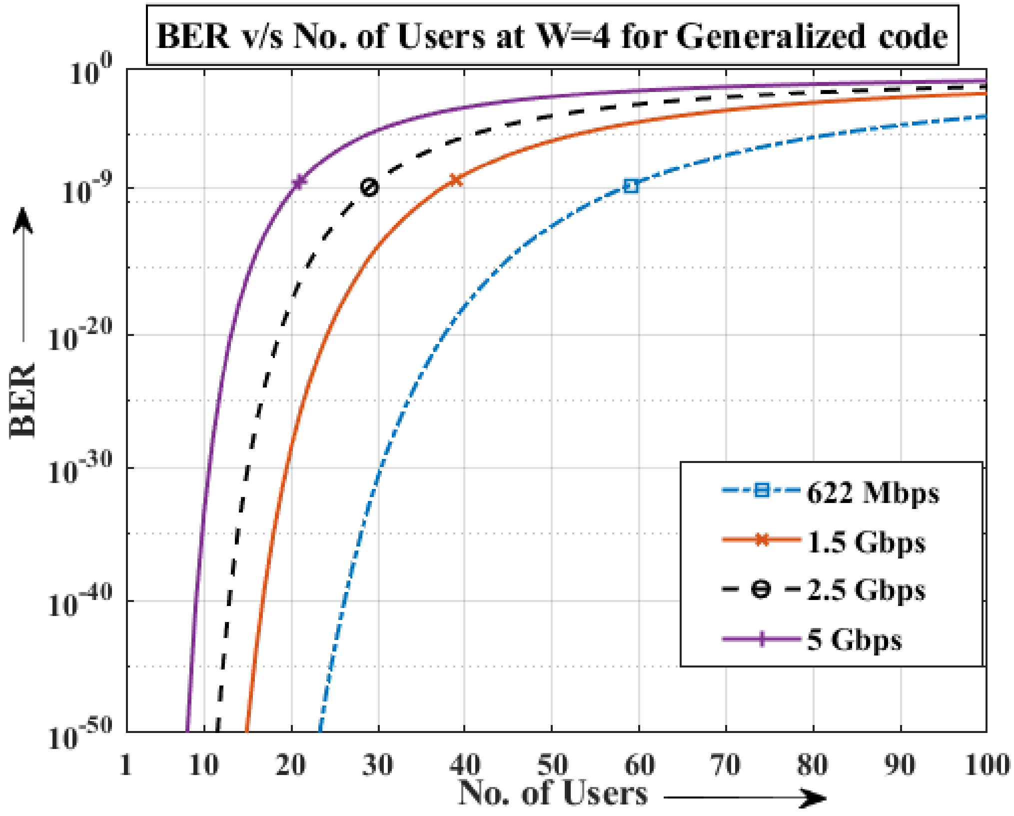

Fig. 7.3 BER versus No. of users for Generalized Code

The figure 7.3 shows the graph of BER versus active no. of users at different data rates for Generalized code for W=4, Psr= –10 dBm based on equation (5.10) and (5.12). From this graph, the Generalized code can support 59, 39, 29, & 21 users with acceptable BER ($<10^{-9}$) at 0.622, 1.5, 2.5 & 5 Gbps data rates respectively.

From the fig. 7.2 & 7.3 it is also observed that the ZCC code gives better BER performance compared to generalized code for different data rates. It can accommodate 29, 19, 16 & 10 more active users than generalized code at 0.622, 1.5, 2.5 & 5 Gbps data rates respectively.

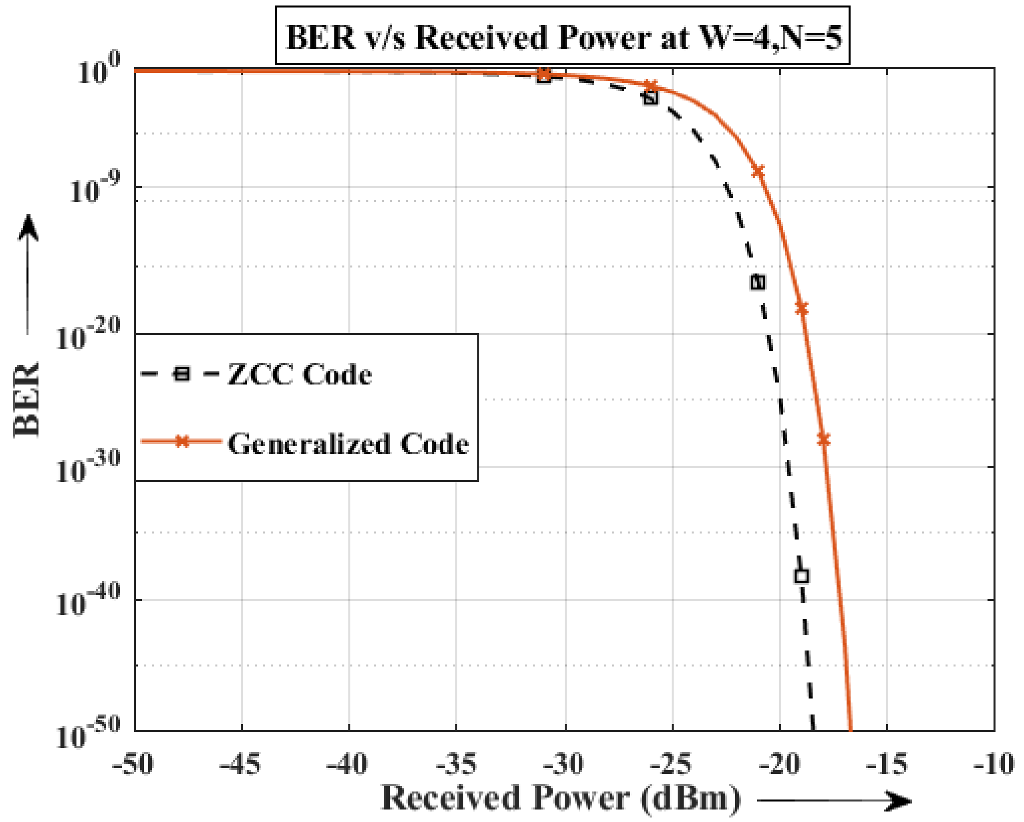

Fig. 7.4 Comparison of BER versus Received Power

The figure 7.4 shows the comparison of BER versus Received power for ZCC and Generalized code at N=5, W=4 based on equation (6.14), (6.16), (5.10) and (5.12).

This graph is obtained at 622 Mbps data rate. The ZCC code gives better BER performance compared to generalized code at lower received power that is ZCC code achieved acceptable BER ($<10^{-9}$) at –23 dBm where as the generalized code achieved the same BER at -21 dBm.

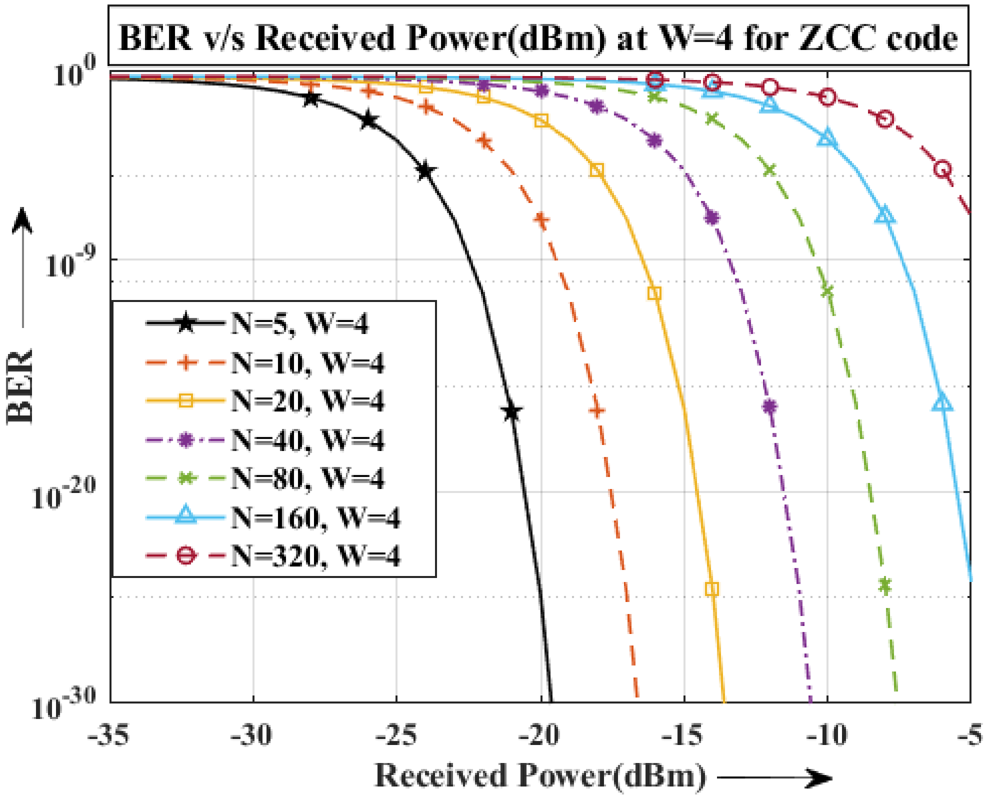

Fig. 7.5 BER versus Received Power for ZCC code for varying active users

The figure 7.5 shows the comparison of BER versus Received power for ZCC code at varying active users that is N= 5, 10, 20, 40, 80, 160 and 320.

This graph is obtained at 622 Mbps data rate and weight W=4.

Figure 7.5 illustrates that if no of active user increases the received power also increases still ZCC code is able to accommodate 80 active users with acceptable BER (10^{-9}) at –11dBm. This can also be verified from figure 7.2 in which it can accommodate 88 users at –10 dBm.

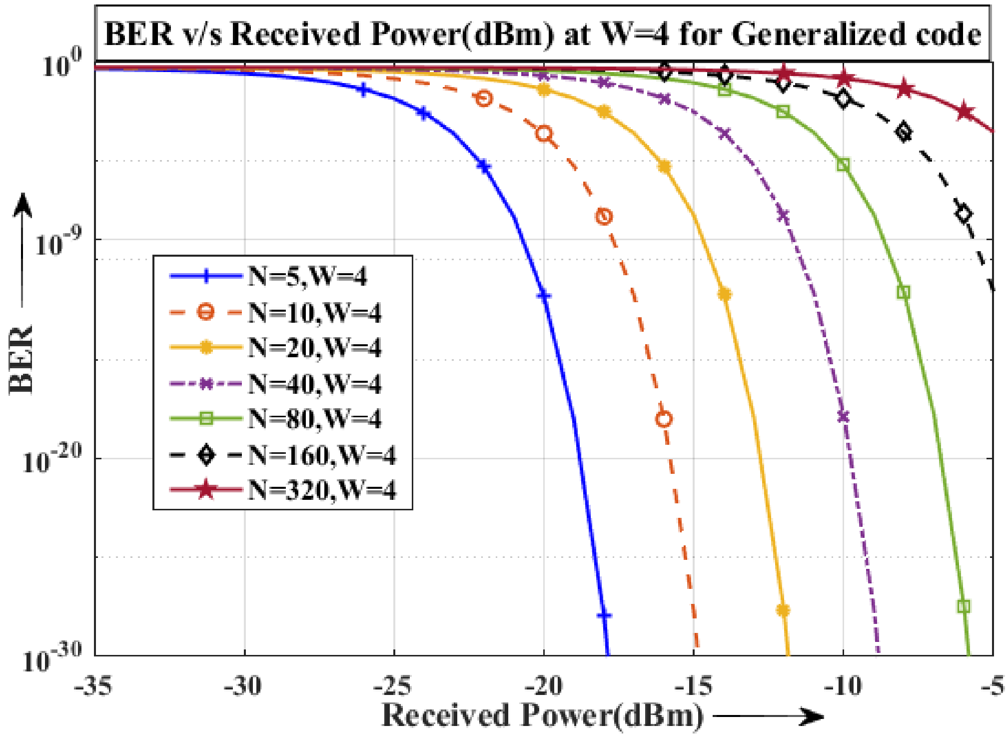

Fig. 7.6 BER versus Received Power for Generalized code for varying active users

The figure 7.6 shows the graph of BER versus Received power for generalized code at varying active users that is N= 5, 10, 20, 40, 80, 160 and 320.

This graph is also obtained at 622 Mbps data rate and weight W=4.
Here generalized code is able to accommodate 40 active users with acceptable BER (10^{-9}) at –12 dBm.
From figure 7.5 & 7.6 it is observed that ZCC code can perform better at lower received power.

7.3. Simulation Results:

➢ **Simulation results for ZCC Code**

These results are obtained using parameter listed in Table 5.1 and ZCC code given in equation (6.11). The simulation setup is given in figure 6.1.

Table 7.3 List of BER values at different FSO range obtained using ZCC code at 622 Mbps

Min BER for ZCC@ 622 Mbps						
Range (Km)	**U1**	**U2**	**U3**	**U4**	**U5**	**Avg. BER ZCC**
0.1	1.80E-13	2.05E-15	4.41E-14	8.95E-14	4.19E-14	**7.15E-14**
0.2	6.81E-13	1.01E-14	2.14E-13	3.06E-13	1.12E-13	**2.64521E-13**
0.3	5.02E-12	2.44E-13	5.56E-12	2.00E-13	1.00E-13	**2.2248E-12**
0.4	2.40E-12	1.97E-12	7.86E-10	2.58E-12	1.41E-12	**1.58872E-10**
0.5	1.70E-11	8.98E-10	4.91E-10	9.16E-11	4.67E-11	**3.08859E-10**
0.6	1.52E-11	1.38E-10	3.30E-10	5.38E-11	5.10E-10	**2.09408E-10**
0.7	2.86E-10	9.63E-09	8.54E-09	5.20E-11	1.09E-10	**3.72341E-09**
0.8	1.12E-10	9.88E-09	2.16E-09	9.57E-10	1.71E-09	**2.96398E-09**
0.9	1.54E-09	1.59E-08	1.98E-09	6.18E-08	1.31E-09	**1.65057E-08**
1	8.09E-08	3.11E-07	5.18E-06	1.75E-08	1.17E-08	**1.12022E-06**

Table 7.4 List of BER values at different FSO range obtained using ZCC code at 1.5 Gbps

Min BER for ZCC Code @ 1.5 Gbps						
Range (Km)	**U1**	**U2**	**U3**	**U4**	**U5**	**Avg. BER ZCC**
0.1	6.13E-10	4.67E-10	9.16E-10	1.62E-10	8.82E-10	**6.08E-10**
0.2	6.41E-09	4.53E-10	1.31E-09	6.73E-09	2.69E-09	**3.5186E-09**
0.3	3.52E-09	1.39E-09	1.28E-09	6.20E-09	2.15E-09	**2.908E-09**
0.4	2.91E-08	1.32E-08	6.61E-08	4.79E-08	3.36E-08	**3.798E-08**
0.5	2.22E-06	8.06E-07	5.01E-08	1.40E-07	8.83E-06	**2.40922E-06**
0.6	1.39E-05	1.48E-05	2.28E-05	7.94E-05	5.81E-05	**3.77958E-05**
0.7	8.61E-04	3.06E-05	1.81E-05	3.78E-05	1.87E-05	**0.000193243**
0.8	2.76E-04	4.53E-03	2.38E-04	8.10E-04	4.31E-04	**0.001256858**
0.9	6.91E-03	2.54E-02	1.81E-04	1.19E-04	1.31E-03	**0.006782858**
1	2.24E-02	1.00E+00	1.15E-03	7.37E-03	1.18E-02	**0.208525534**

- **Simulation results for Generalized Code**

These results are obtained using parameter listed in Table 5.1 and Generalized code given in equation (5.7). The simulation setup is given in figure 5.2.

Table 7.5 List of BER values at different FSO range obtained using generalized code at 622 Mbps

Min BER for Gen. Code @ 622 Mbps						
Range (Km)	**U1**	**U2**	**U3**	**U4**	**U5**	**Avg. BER Gen. Code**
0.1	1.46E-11	1.09E-13	2.60E-13	2.10E-11	1.49E-12	**7.49113E-12**
0.2	6.51E-10	4.90E-11	4.60E-10	5.16E-10	2.80E-11	**3.40786E-10**
0.3	2.71E-10	1.56E-11	3.58E-10	2.41E-10	1.85E-11	**1.8082E-10**
0.4	2.71E-09	1.10E-11	9.27E-10	6.99E-09	1.40E-11	**2.1304E-09**
0.5	2.07E-09	7.85E-10	1.25E-10	5.24E-09	4.66E-10	**1.7372E-09**
0.6	1.56E-09	5.35E-09	8.03E-09	6.93E-08	2.61E-10	**1.69009E-08**
0.7	9.50E-08	3.70E-09	1.20E-09	8.32E-07	9.83E-09	**1.88346E-07**
0.8	7.13E-08	2.43E-08	7.11E-08	1.29E-06	9.01E-09	**2.93141E-07**
0.9	5.22E-07	1.68E-07	8.54E-07	7.95E-05	6.89E-06	**1.75868E-05**
1	2.48E-05	1.48E-05	0.0010528	1.37E-05	1.61E-06	**0.000221542**

Table 7.6 List of BER values at different FSO range obtained using generalized code at 1.5 Gbps

	Min BER for Gen. Code @ 1.5 Gbps					
Range (Km)	**U1**	**U2**	**U3**	**U4**	**U5**	**Avg. BER Gen. Code**
0.1	6.22E-09	4.84E-09	6.22E-10	8.26E-09	2.36E-09	**4.4604E-09**
0.2	3.80E-09	7.12E-08	5.55E-09	6.67E-08	8.52E-08	**4.649E-08**
0.3	1.45E-08	8.82E-06	5.54E-07	4.43E-07	7.73E-06	**3.51236E-06**
0.4	6.04E-06	3.53E-05	5.49E-06	2.68E-06	2.19E-06	**0.00001034**
0.5	1.71E-04	2.48E-04	8.80E-05	2.72E-05	7.35E-05	**0.00012154**
0.6	1.55E-03	2.12E-04	4.03E-04	1.48E-04	1.05E-05	**0.0004647**
0.7	7.76E-02	1.45E-03	2.21E-03	1.92E-03	3.70E-04	**0.01671**
0.8	2.44E-02	5.33E-02	1.96E-02	3.04E-02	1.33E-03	**0.025806**
0.9	1.37E-02	3.91E-02	1.00E+00	1.68E-02	2.97E-02	**0.21986**
1	1.00E+00	1.00E+00	1	1.31E-02	2.90E-02	**0.608412856**

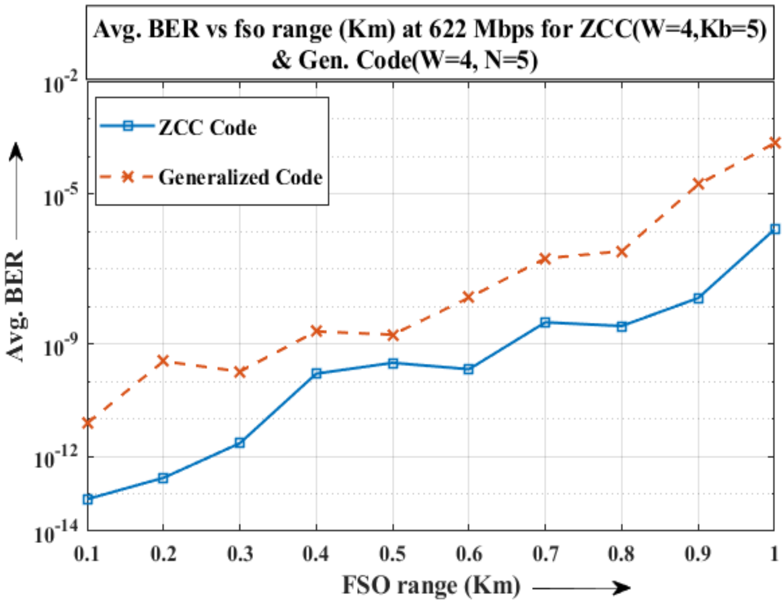

Fig. 7.7 Comparison of BER versus FSO link range at 622 Mbps

The figure 7.7 shows the graph of BER versus FSO link range for generalized code and ZCC code at 622 Mbps. Table 7.3 & 7.5 is used in this graph.

In this figure, it is observed that ZCC code gives better performance in terms of BER under turbulence condition at 622 Mbps data rate. ZCC code achieved BER ($<10^{-9}$) at 650 meters where as the generalized code achieved the same BER at 500 meters.

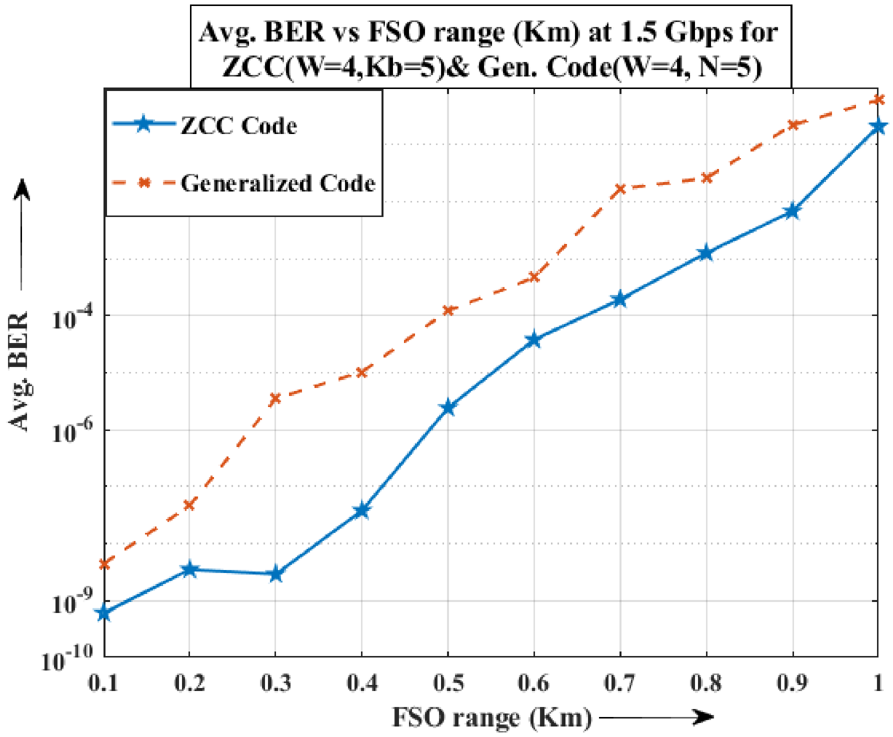

Fig. 7.8 Comparison of BER versus FSO link range at 1.5 Gbps

Similarly, figure 7.8 is obtained as per data given in table 7.4 & 7.6.

In figure 7.8, ZCC and Generalized is compared in terms of BER versus FSO range at 1.5 Gbps over FSO channel. At 1.5 Gbps, ZCC code performs better than generalized code as shown in figure 7.8.

Chapter 8

Conclusion & Future Aspects

In this project the generalized code and Zero Cross–correlation code is numerically analyzed for BER versus no. users & BER versus received power at different data rates.

Also the five users SAC–OCDMA system is implemented using these codes for FSO channel for different data rates and link range.

The performance of the SAC–OCDMA system is analyzed under turbulence and 8.68 dB/km atmospheric attenuation for both codes keeping code weight (W=4) & No. of users (N=5) constant.
The 8.68 dB/km atmospheric attenuation is generally considered for heavy rain environment.

All numerical & simulation results have been discussed in chapter 7.

Finally, it is concluded that at the cost of increased code length, the zero cross – correlation code gives better performance than generalized code in numerical results as well as in simulated results.

As we know that longer code length will require more equipment in encoding and decoding process. However the generalized code is cost effective, but it cannot support large no of users then ZCC.

In future, the efficiency of the OCDMA system can be enhanced through suitable code and encryption schemes such as SAC-OCDMA, 2D-HC codes, Multicode, Variable weight code, EDW & MDW codes.

By using an appropriate detection method, system performance can be improved for example direct detection method which offers more users with fewer components in comparison to a balanced detection method.

More research on this subject can involve increasing the number of users using 2D and 3D codes implementing in real-time, improving the design of encoders, decoders and detection mechanisms.

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