Performance Analysis of Optical CDMA Using W/T Codes

A Dissertation submitted towards the partial fulfillment of
the requirement for the award of degree of

Master of Technology

In

Microwave and Optical Communication Engineering

Submitted By

Sunny
09/MOC/2010

Under the supervision of

Mr. Rajesh Birok
(Associate Professor)

Department of Electronics and Communication Engineering

&

Department of Applied Physics

Delhi Technological University

(Formerly Delhi College of Engineering)

Certificate

This is to certify that the dissertation title ***"Performance Analysis of OCDMA System Using Wavelength/Time codes"*** is the authentic work of **Mr. Sunny** under my guidance and supervision in the partial fulfillment of requirement towards the degree of Master of Technology in ***Microwave and Optical Communication Engineering***, jointly run by the Deptt.of Electronics and Communication Engineering and Deptt.of Applied Physics in ***Delhi Technological University.***

Rajesh Birok
Supervisor
Associate Professor
Deptt. of ECE
Delhi Technological University

Prof. Rajiv Kapoor
HOD
Deptt. of ECE
Delhi Technological University

ACKNOWLEDGEMENT

I am indebted to my thesis supervisor **Mr. Rajesh Birok**, Department of Electronics and Communication, for his gracious encouragement and very valued constructive criticism that has driven me to carry the project successfully.

I am deeply grateful to **Prof. Rajiv Kapoor**, Head of Department (Electronics and Communication Engineering), Delhi Technological University for his support and encouragement in carrying out this project.

I wish to express my heart full thanks to my branch coordinator **Prof. R.K Sinha, Dr. Ajeet Kumar, Dr. Priyanka Jain, Mr. Rajesh** and friends for their goodwill and support that helped me a lot in successful completion of this project.

Finally I express my deep sense of gratitude to my parents and almighty God for their blessings without which this project was not possible.

Sunny

M.Tech (MOCE)

09/MOC/2k10

Table of Contents

List of Tables

List of Figures

Abbreviations

1-D	One Dimensional
2-D	Two Dimensional
CD	Code Dimension
BER	Bit Error Rate
CDMA	Code Division Multiple Access
LAN	Local Area Network
NRZ	Not Return To Zero
FDMA	Frequency Division Multiple Access
FOCDMA	Fiber Optic Code Division Multiple Access
MAI	Multiple Access Interference
OCDMA	Optical Code Division Multiple Access
OOC	Optical Orthogonal Code
OOK	On-Off Keying
PRBS	Pseudo Random Bit Sequence
PSO	Pseudo Orthogonal
RZ	Return to Zero
SNR	Signal to Noise Ratio
TDMA	Time Division Multiple Access
WDM	Wavelength Division Multiplexing
WHTS	Wavelength Hopping Time Spreading
ZCC	Zero Cross Correlation

ABSTRACT

The OCDMA system plays a vital role in long haul and high speed communication networks like LAN and MAN. These systems have advantage of high speed, large capacity and huge bandwidth.

The TDMA, WDMA and CDMA are available major multiple access techniques. The throughput of the TDMA system is limited by product of number of user and their respective transmission rate. In WDMA system each channel is transmitted on a single wavelength of light. This allows each user to transmit the peak speed of network hardware, but the complexity of the system increases due to dynamic system of multiple users because of the significant amount of the coordination among the nodes required for successful operation. If a dynamic user base has to built with WDMA system the control channel and collision detection schemes would need to be implemented but that would waste significant bandwidth. Both TDMA and WDMA system require time or frequency management system however the CDMA system does not require any centralized control and thereby reduce the complexity of the system. Optical CDMA combines the large bandwidth of the fiber medium with the flexibility of the CDMA technique to achieve the high-speed connectivity.

The establishment of OCDMA needs to overcome the code orthogonality problem and also in 1-D optical orthogonal codes, the ratio of code length to the code weight grows rapidly as the number of users increases. If we consider 2-D optical orthogonal code then, it reduce the length of the code as a result of which BER performance of the system improves. Wavelength-Time (W/T) encoding of the two dimensional code is practical in FOCDMA networks. They can be classified mainly into two types:

1. Hybrid sequences, where one type of sequence is crossed with another to improve the cardinality and the correction properties and
2. Matrix codes 1-D sequence converted to 2-D codes or 2-D codes by construction to reduce the time spread of the sequences /codes.

In the project I have discussed the performance analysis of an incoherent optical code division multiple access scheme based on wavelength/time codes. The OCDMA system can support only 25 users for permissible BER rate of 10^{-9} with -15dB received power. The performance of the system is also analyzed on BER and EYE diagram under the influence of number of simultaneous users with different received power.

CHAPTER 1

INTRODUCTION

1.1 Review of Optical fiber Communication-:

The optical fiber communication deals with the transmission of information signal from one place to another in the form of light through optical fiber. With the help of optical fiber communication, the high quality and high speed telecommunication systems can be achieved. Optical fiber communications has revolutionized the telecommunication industry.

Often the optical fiber offers much higher speed than the speed of electronic signal processing at both the ends of fiber. Because of several advantages of optical fiber communication over electrical transmission, the use of optical fiber has largely replaced the copper wire in communication industry.

The main benefits of fiber optic communication include

- Low Loss
- Less number or repeaters required
- High data carrying capacity
- Very Large Bandwidth
- Low crosstalk
- High speed
- Reliable system

So, far the development of optic fiber communication has proceeded through four generations.

The first generation optical fiber system used short wavelength of 0.85μm and multimode fibers, which used material, based on quartz having diameter of 50μm and loss was 4 dB/Km. The light source was a Light Emitting Diode (LED) made from group III-V semiconductor compound & alloys e.g. Aluminum Gallium Arsenide (AiGaAs), and the optical detector was a P-i-N (PIN) photodiode or Si Avalanche Photodiode (APD). The first generation optical fiber communication system were mainly used in the link among central offices and transmitted digital signal with less than third level (E3) of pulse code modulation.

The second generation optical fiber communication system used long wavelength with 1.31 μm single-mode fibers whose loss had been reduced from 4dB/Km to 0.5 dB/Km. LEDs made from group III-V semiconductor, the quaternary alloy InGaAsP, or Laser Diode (LD) was used as light sources and lnGaAs-PiN / GaAs-FETs were used as optical detectors. The second generation was suitable for being used in the links among central offices with the bit rate of 140 Mbps or long haul links with high bit rate of 400-565 Mbps and distance could achieve 40 Km without repeaters.

The third generation optical fiber communication used dispersion shifted single-mode fibers with wavelength of 1.55μm , with loss reduced to 0.2 dB/Km. They can be used in long-haul telecommunications or submarine long-span telecommunications with a high bit rate of 2.5Gbps and lnGaAsP LD light source or a Distributed Feedback (DFB) LD.

The fourth generation optical fiber communication use non-zero dispersion single mode fiber with 1.55μm and WDM, using optical amplifiers such as Erbium-Doped fiber amplifier (EDFA), and Raman amplifier used to increase the transmission distance. The data rate per wavelength is in the range 2.5Gbps to10Gbps.

The research efforts on the new generation optical fiber communication system are accelerating. Its trends are to boost the bit rate of a single wavelength channel further to increase the transmission capacity of the system, to extend the transmission distance, and to develop ultra large capacity, ultra long distance and optical fiber networking, such as a 40Gb/s system for a single wavelength, ultra-wide bandwidth optical fiber amplifier in C, L and S wave band, dynamic dispersion compensation, Optical Code-Division Multiple Access (OCDMA) , coherent light communication, optical soliton communication and intelligent optical networking etc. These new technologies for optical fiber communication lead to improved optical communication system and the network.

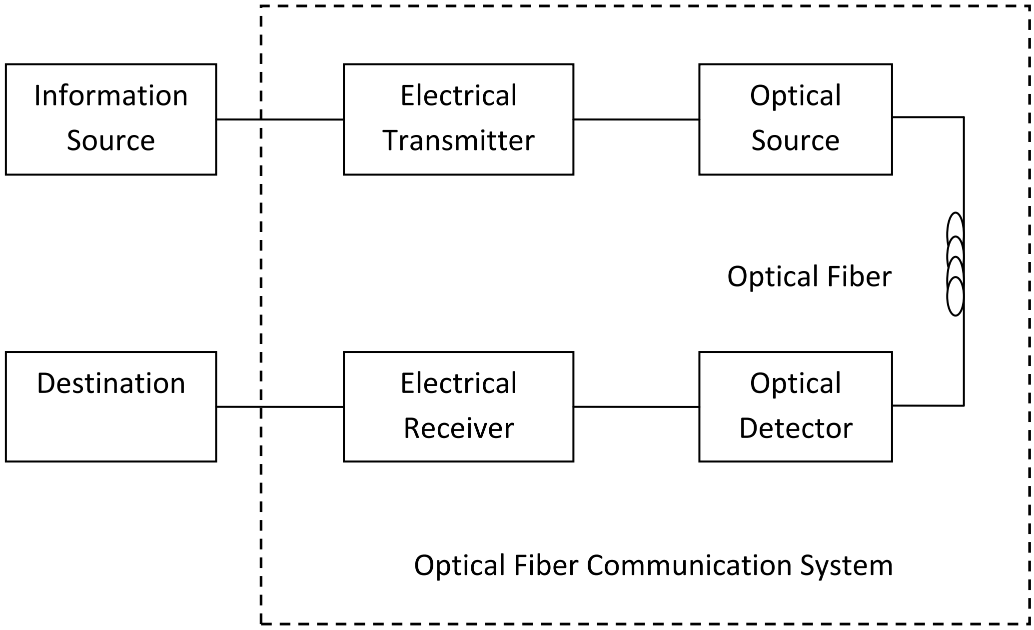


Figure 1.1 Optical Fiber Communication Systems

The block diagram for optical communication is shown In figure 1.1. In this case the information source provides an electrical signal to a transmitter comprising an electrical stage, which drives an optical source to give modulation of light wave carrier. The optical source which provides the electrical optical conversion may be either a semiconductor laser or the Light Emitting Diode (LED). The transmission medium consists of an optical fiber cable or the receiver consists of an optical detector, which drives a further electrical stage and hence provides demodulation of the optical carrier. Photodiodes (P-N, P-i-N or Avalanche) and in some instances, phototransistor and photoconductors are utilized for the detection of the optical signal and optical electrical conversion. Thus there is a requirement for electrical interfacing at either end of optical link and at present the signal processing is usually performed electrically.

1.2 MULTIPLE ACCESS TECHNIQUES

The major multiple access protocols are
Wavelength Division Multiple Access (WDMA)
Time Division Multiple Access (TDMA)
Code Division Multiple Access (CDMA)

1.2.1. Wavelength Division Multiple Access:

WDMA is one of the earliest multiple-access techniques for cellular systems when continuous transmission is required for analog services. In WDMA system, bandwidth is divided into number of channels and each channel occupies a narrow optical bandwidth around a center wavelength or frequency The channels are assigned only when demanded by the users. Therefore when a channel is not in use it becomes a wasted resource. Because each channel is transmitted at a different wavelength, they can be selected using an optical filter. In this, each user is assigned a fixed slot of wavelength all the time which makes it simple to implement and use.

1.2.2 Time Division Multiple Access:

In TDMA, the entire bandwidth is available to the user but only for a finite period of time. In most cases, the available bandwidth is divided into fewer channels compared to FDMA and the users are allotted time slots during which they have the entire channel bandwidth at their disposal. In a TDMA system, each channel occupies a pre-assigned time slot, which interleaves with the time slots of other channels. Global Systems for Mobile communications (GSM) uses the TDMA technique.

TDMA requires careful time synchronization since users share the bandwidth in the frequency domain. Since the number of channels are less, inter channel interference is almost negligible, hence the guard time between the channels is considerably smaller. Guard time is spacing in time between the TDMA bursts. TDMA uses different time slots for transmission and reception. In cellular communications, when a user moves from one cell to another there is a chance that user could experience a call loss if there are no free time slots available.

1.2.3 Code Division Multiple Access :

Code division multiple access (CDMA) is a form of multiplexing and a method of multiple access to a physical medium such as a radio channel, where different users use the medium at the same time using different code sequences. In CDMA, every user will be allocated the entire spectrum all of the time. CDMA uses unique spreading codes to spread the baseband data before transmission. The signal is transmitted in a channel, which is below noise level. The receiver then uses a correlator to dispread the wanted signal, which is passed through a narrow band pass filter. Unwanted signals will not be dispread and will not pass through the filter. Codes take the form of a carefully designed one/zero sequence produced at a much higher rate than that of the baseband data. The rate of a spreading code is referred to as chip rate rather than bit rate.

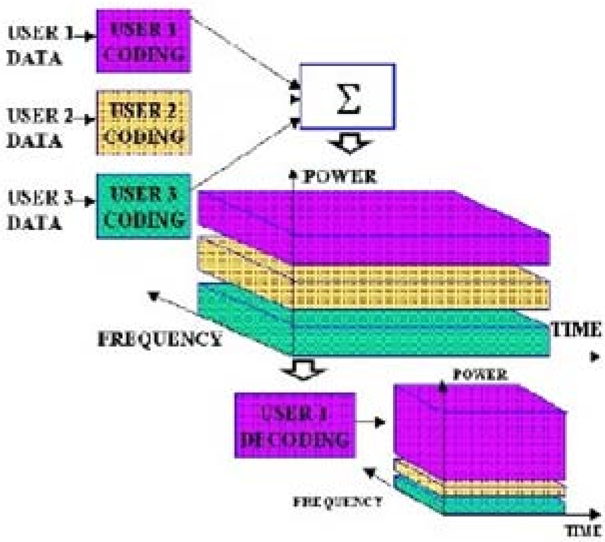


Figure 1.2 CDMA spreading

Spread spectrum code division multiple access (CDMA) allows asynchronous multiple access to a Local Area Network (LAN) with no waiting. The additional bandwidth required by spread spectrum can be accommodated by using a fiber-optic channel and incoherent optical signal processing. Optical CDMA is a scheme which is used for multiplexing optical communication channels that is based on the method of direct-sequence spread spectrum.

1.3 Evolution of OCDMA-:

In the late 1970's, code division multiple access (CDMA) technology was aimed at military communication, which was a spread frequency technique increasing the robust security of information transmission. Spread frequency communication has been used in military communications for a long time in order to resist intended interference and implement low probability of detection. These days CDMA has widely used in the field of wireless communication, especially, the third generation wireless communication systems. OCDMA is technology to realize multiplexing transmission and multiple accesses by coding in optical domain, which supports multiple simultaneous transmissions in the same timeslot and same frequency. It is another technology of multiplexing and multiple access besides Optical Time Division Multiplexing (OTDM) and Wavelength Division Multiplexing (WDM) and a potentially promising technique for optical networks in the future, and especially, due to its easy access and flexible network structure, it is very applicable to the access network.

In 1986, Prucnal, Santoro and fan proposed to realize the fiber-optic LAN by using optical signal processing [3,4] and used prime codes to carry out the experiment of electronic encoding and fibre optic delay line decoding, verifying the feasibility to implement incoherent OCDMA system by encoding in the time domain. In 1988, Weiner, Heritage and salehi[2] demonstrated how to spread the femto-second optical pulse into Pico-second-duration pseudo-noise bursts. The spread frequency was achieved by encoding the light spectrum into pseudorandom binary phase and then by decoding could be applied to the fast reconfigurable OCDMA communication networks. Both breakthrough studies were milestones for the development of OCDMA.

Optical encoding and decoding for incoherent OCDMA uses unipolar codes whereas the bipolar codes used in RF CDMA (Radio Frequency Code Division Multiple Access) have poor performance in OCDMA system and cannot be used. Therefore, unipolar codes with good system performance need to be developed. Consequently, in the earlier years, the research on incoherent OCDMA focused on looking for and obtaining unipolar codes with good auto-and cross-correlations, such as OOC (Optical

Orthogonal/Pseudo-Orthogonal Codes)[1,8], PC (Prime Codes), QCC (Quadratic Congruence Codes)[9] etc. In order to improve the performances of PC and QCC, EPC (Extended Prime Codes)[10] ,MPC (Modified Prime Codes)[11] and EQCC (Extended Quadratic Congruence Codes)[1,2] have been proposed again. Among these one dimensional codes, OOC has the best performance but its construction is complicated, compared with those of other codes. Although one-dimensional OOC possesses the ideal auto and correlation, and its cardinality, that is, the number of codeword, is the largest, the number of users is inversely proportional to the length of time spread. Meanwhile, the cardinality of code is approximately inversely proportional to the square of the code-weight. And moreover, the smaller the code-weight becomes, the more the error probability increases. In order to meet the requirement of bit-error-rate, the simultaneous number of active users in the network must be reduced.

Owing to the reasons mentioned above, the application of one-dimensional codes to incoherent OCDMA system is limited. In order to increase the number of users, unipolar codes with larger capacity need to be designed. Therefore, starting around 1990, researchers transferred their interests from the study on one-dimensional codes to 2D (two-dimensional) OOC's which enormously increase the capacity of the system and improves the performance. Great progress has been made in aspects of the encoding algorithm and the hardware implementations of encoder and decoder of incoherent OCDMA and the experimental system and the network protocols of OCDMA, and many OCDMA system and network experiments in the laboratories in the field have been performed. An OCDMA network demonstration experiment with star structure done by Princeton University in America was reported in IEEE Photonics Technology Letters in 2006. The experiment was operated at 115Gchip/s. This demonstration used off-the-shelf devices to implement 2-D wavelength-time incoherent OCDMA encoding, with a single user bit rate of 5 GB/s and 10^{-13} bit-error-rate or better.

1.4 Characteristics of OCDMA-:

OCDMA has become a promising technology to implement truly all optical communication and networking that uses optical signal processing directly, combining the advantage of electrical CDMA with the bandwidth predominance of fibre-optic and optical signal processing devices. The Passive optical access network, LAN and WAN, can be built up by using OCDMA technology The combination of OCDMA with WDM or TDM can enhance signal multiplexing and label switching through the combination of OCDMA with WDM or/and IP over WAN so that transmission and switching capacity of network can be enhanced and performance of the communication network can be heightened.

OCDMA can implement high-speed transmission, switching and add/drop of data through using all-optical signal processing and thus it can realize all-optical communication and all-optical networking and overcome the effect of electronic bottleneck, which exists in the electronic node in the traditional network.

1. Subscribers can access the network at random and the network has soft capacity. Meanwhile, the pattern of networking is very flexible.

2. OCDMA does not need buffering in queue because it uses the tell-to-go protocol.

3. OCDMA network can assign the bandwidth dynamically and implement the bandwidth assignment with different granularities deftly, and used optical network bandwidth effectively.

4. The traffic protocol and network topology are transparent in the OCDMA network. OCDMA can support variable bit-rate traffic and bursty traffic and implement differential QoS according to demand. OCDMA network can be upgraded and extended.

5. An OCDMA network is somewhat secure and cryptic for the transmission information.

6. An OCDMA network needs fewer devices than a WDM network and its equipment is simple, and implementing cost of OCDMA network is low. A DWDM network needs accurate wavelength control and conversion. Furthermore, OCDMA is highly compatible with DWDM and TDM.

7. OCDMA networks employ distributed management, which is simple and it is convenient to locate network failure and protect and recover. Because of the advantages mentioned above, OCDMA can support multimedia including voice, data, video, including IP traffic, video-on-demand, streaming media.

1.5 Classification of OCDMA system -:

Optical CDMA systems can be divided into two broad categories based on the way in which a particular user's code is applied to the optical signal. These classifications include:

1) **Coherent optical CDMA**
2) **Incoherent optical CDMA**

In a coherent OCDMA system, a given user's code is generally applied via phase coding of the optical signal field, which is often derived from a highly coherent wideband source, such as a mode-locked laser. The receiver for a coherent OCDMA system relies on a coherent reconstruction of the signal field to recover the decoded user's data. In this the signals are bipolar in nature. Coherent systems achieve higher performance than the incoherent ones but require high-precision control of the optical path within the encoder and decoder In contrast an incoherent OCDMA system typically relies on amplitude-modulated codes rather than directly manipulating the optical phase. Also, the receiver is based upon an incoherent decoding and recovery process. A number of incoherent OCDMA system architectures utilize wideband

incoherent sources, such as a broadband amplified spontaneous emission source, while other incoherent architectures utilize coherent laser sources as part of their implementation. In most incoherent OCDMA systems, each user is assigned a specific code sequence: a coded transmission is sent to represent a data bit “1,” and a null is used to represent a bit “0.” Due to the incoherent nature of the system, there are no negative signal components and the signals are unipolar. To avoid loss of code confidentiality using simple energy level detectors, these schemes can be modified to assign two codes per user a 1 being represented by a code and a 0 being represented by another .Incoherent systems are regarded as more practical because the light sources and encoding and decoding techniques have low complexity and are cost effective.
If we categorize them depending on the differences of coding approaches for optical signals, there are six kinds of OCDMA system.

1. Direct-sequence or temporal encoding OCDMA systems, also known as spread-spectrum encoding OCDMA systems
2. Spectral amplitude encoding OCDMA systems;
3. Spectral phase encoding OCDMA systems;
4. Temporal phase encoding OCDMA systems;
5. Two dimensional spatial encoding OCDMA systems, also known as spread space encoding;
6. Hybrid encoding OCDMA systems;

This kind of system uses a combination of the encoding approaches mentioned above. We can acquire two-dimensional encoding, for instance, Wavelength Hopping/ Time Spread (WH/TS) encoding, through using the combination of spectrum encoding with temporal encoding. If space encoding is combined with WH/TS encoding again, space-spread/ wavelength hopping/ time-spreading encoding (SS/WH/TS) can be obtained and the other options may be deduced by analogy.

Options (1), (2) and (5) refer to incoherent OCDMA systems, (3) and (4) are coherent OCDMA systems, and (6) may be either. If we sort them according to the amount of resources of time, wavelength and spaced used, they can be divided into one-dimensional systems, two-dimensional systems and three-dimensional systems. The afore mentioned types of (1), (2), (3) and (4) belong to one-dimensional systems, (5) is two-dimensional system, and the system with greater than two dimensions can be implemented by (6). If the polarization is also taken in account, the four-dimensional systems can be obtained.

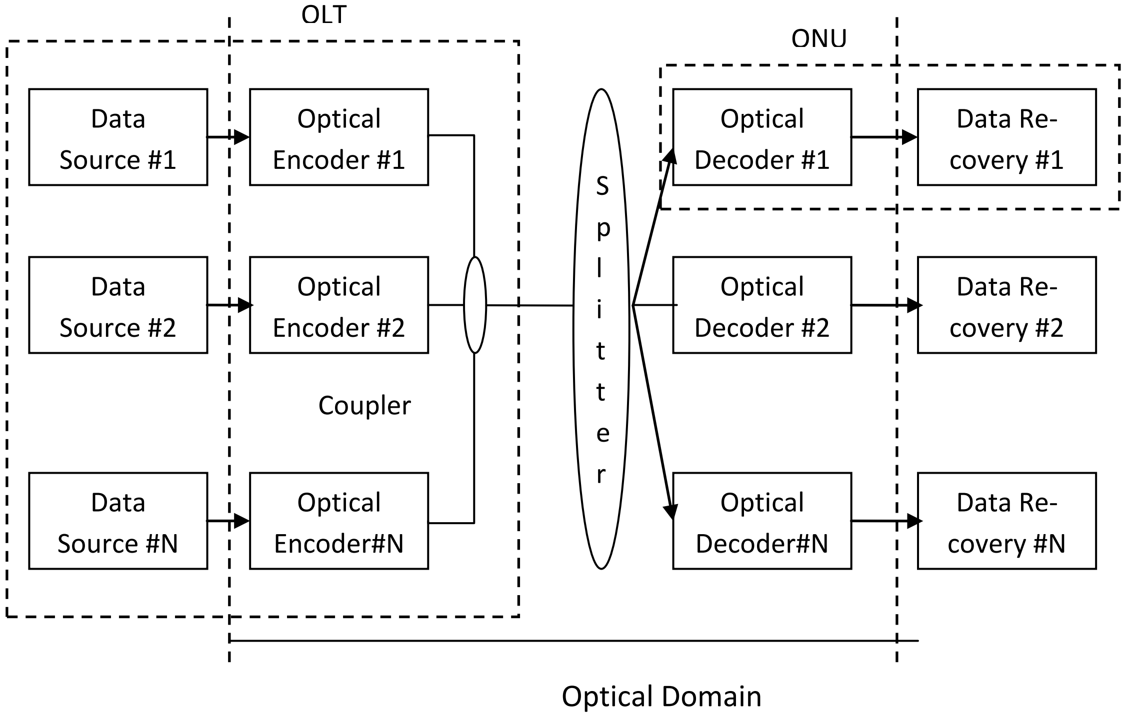


Figure 1.3 Typical diagram of OCDMA System

The block diagram of OCDMA system is shown in figure 1.3. On transmitter side, data bits obtained in electrical form are converted in to narrow optical pulses by narrow band electrical to optical converters and then fed into an encoder to generate the optical sequences which are then coupled into an encoder to generate the optical sequences which is then coupled in to the fiber. Each receiver is given a unique address code from orthogonal set of codes. Since each receiver is fixed tuned to a unique code, CDMA encoder must be tunable to talk to any of the users in the system. On the receiver side, a fixed tuned match filters recovers the signal in the presences of MAI. This is possible because the match filter de-spreads only the match signal leaving behind the MAI signal still spread. The output of the decoder is threshold detected and then converted to electrical form by an optical-to-electrical (O/E) converter.

CHAPTER 2

DEVELOPMENTS IN OCDMA

2.1 Background-:

The history of OCDMA dates back to the 1970s and as literatures from various sources is discussed in brief as below.

A.Stok et.al.[14] proposed the OCDMA as a natural solution to achieving asynchronous high-speed connectivity in a local area network environment. OCDMA is shown to 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. The limitation of 1-D optical orthogonal code for CDMA have motivated the idea of spectral spreading in both temporal and wavelength domains. It is found that if the constraints on constant weights in these 2-D codes are relaxed, differentiated levels of service at the physical layer become possible.

L. Tanceski[22] et al. introduced an incoherent optical code division multiple access CDMA) concept using a combination of wavelength hopping and time spreading employing prime-hop sequences, which feature an autocorrelation function with zero side lobes and cross correlation function of at most 1. Consequently, the number of stations in the network and the number of simultaneous users that can he supported is greatly increased. The system is suitable for truly asynchronous highly secure LAN applications.

Antonio J. Mendez et al. [13] presented a technique for generating PSO matrices from sets of optimum Golomb rulers. It is shown that 2-D codes have higher cardinality and good spectral efficiency, especially when compared to linear or direct sequence code. This Thesis describes the design and construction of the matrices; analyzes their performance from a communications viewpoint; describes their use as codes for the asynchronous, concurrent communication of multiple users; and analyzes the bit error rate performance based on capturing and modeling a typical network topology and performing a numerical modeling of the system.

A. J. Mendez et al.[23] demonstrated that code division multiple access permits concurrent Communication over all virtual channels (in principle), independent of the data rate and the network size. In reality, most CDMA approaches have a bandwidth penalty due to the code length and a loss penalty due to the broadcasting required by CDMA. Both of these penalties can be reduced or ameliorated by means of multi-attribute coding. Matrices constructed from relatively inefficient (0, 1) pulse sequences are suitable multi-attribute non-coherent CDMA codes which are both bandwidth and broadcast efficient. A novel approach to synthesize matrix CDMA codes is exhibited; a 4 x 4 physical model is developed, and concurrent communication at concurrent data rates of 100, 150 and 250 Mbps per port is demonstrated experimentally.

D.E. Leaird et al[26] experimentally investigated spectrally phase coded OCDMA with a modulation format based on switching between two codes. The code switching data modulation format enhances security compared to On-Off keying by eliminating a vulnerability to eavesdropping based on a simple energy detector.

Hwan S Chung et al.[27] experimentally demonstrated a security improved optical code division multiplexed access scheme based on spectrally encoded incoherent broadband light source with bipolar coding. The details of coding scheme are shown and security issues have been investigated by measuring eye diagrams and bit error rates for various cases. The analytical and numerical simulation results are presented for secure transmission of spectrally encoded incoherent optical CDMA signal.

Bin Ni et al. [15] studied the effect of the coherence time of light sources on the performance of an incoherent temporal-spreading optical-code-division multiple-access (OCDMA) system. Broadband noise-like light sources, such as amplified spontaneous emission sources, are used by the transmitters. Three different kinds of receiver structures are examined and compared. Results show the impact of the non ideal light sources on the system performances relative to the ideal case. Analysis shows that to achieve the best performance when the available optical bandwidth and data rate are fixed, there is an optimal range for the spreading code length.

K.Yu et al. [16] proposed a two-dimensional (2-D) code family and transmitter/receiver structures for incoherent multi-wavelength- time spread optical CDMA networks. The combination of metal-coated reflection delay lines and arrayed waveguide gratings gives the proposed optical coder/decoder much enhanced flexibility in accommodating different code sets. Successful encoding/decoding has been demonstrated on signals up to 3-GHz time-chip rate with 4 * 15 code words.

Anuar et al. [17] proposed a new code structure for Spectral-Amplitude Coding Optical Code Division Multiple Access (OCDMA) system with zero cross-correlation. In contrary to the existing code, Zero Cross-Correlation (ZCC) code provides much better performance of Bit Error Rate (BER) due to non-existence of Phase Induced Intensity (PIIN) noise. The newly proposed code can adapt to any variable number of weight and user without any constraint by using transformation and mapping technique respectively. It is theoretically demonstrated to compare the performance of ZCC code with the existing codes such as Hadamard, Modified Frequency Hopping and Modified Double-Weight (MDW) codes. For typical error rate of optical communication system, 10-9, it can accommodate 84 users simultaneously.

S.A. Aljunid et al. [18] proposed a new code structure for spectral-amplitude-coding optical code-division multiple-access system based on double weight code families. The DW code has a fixed weight of two. It is shown that by using a mapping technique, codes that have a larger number of weights can be developed. Modified double-weight code is a double weight code family variation that has variable weights of greater than two. The newly proposed code possesses ideal cross-correlation properties and exists for every natural number. Based on theoretical analysis and simulation, MDW code is shown here to provide a much better performance compared to Hamadard and modified frequency-hopping Technique.

Chung et al. [19] introduced the notion of optical orthogonal codes and addressed their applications to a variety of areas in communications. Methodologies in the design and analysis of optical orthogonal codes with tools from projective geometry, the greedy algorithm, iterative constructions, algebraic coding theory, block designs and various other combinatorial disciplines are discussed.

Jawad A. Salehi [1] examined fiber-optic code division multiple access (FO-CDMA) communications techniques. A new class of codes (signature sequences), namely, optical orthogonal codes (OOCs), that are suitable for (FO-CDMA) are introduced. An experiment that shows the desired auto- and cross-correlation properties of these codes and their use in FO-CDMA is reported. Furthermore, the concept of optical disk patterns, an equivalent way of representing OOC's is introduced. The optical disk patterns are used to derive the probability density functions associated with any two interfering OOC's. Also presented is a detailed study of different interference patterns from which the strongest and the weakest interference patterns are introduced.

M.S. Anuar et al. [17] proposed a new code structure for spectral amplitude coding Optical code division multiple access systems with zero cross-correlation and theoretically demonstrated the performance of this code by using direct decoding technique. The proposed code be adapted to any weight and user by using transformation and mapping techniques, respectively. The direct decoding technique is exploited since there is no overlapping in the code construction. The code performance shows that it outperforms the existing SAC OCDMA codes such as Hadamard, Modified Frequency Hopping (MFH), and Modified Double Weight (MDW).

I.B. Djardjevic et al. [20] proposed three novel classes of optical orthogonal codes (OOCs) based on combinatorial designs. It is shown that hey are applicable to both synchronous and asynchronous incoherent optical code-division multiple access and compatible with Spectral- Amplitude-Coding (SAC), fast frequency hopping, and time-spreading schemes. Simplicity of construction, larger codeword families, and larger flexibility in cross-correlation control make the proposed OOC families interesting candidates for future OCDMA applications. A novel balanced SAC receiver for multiuser interference cancellation that can handle unequal in-phase cross correlation of OOC is also proposed. The upper bound on the bit-error rate as a function of the number of users in SAC schemes is given for all proposed OOC classes.

S. Yegnanarayanan et al. [21] demonstrated a new technique for implementation of fast wavelength-hopping incoherent OCDMA. The output pulse from a mode locked laser is spectrally broadened through super-continuum generation. This pulse is then encoded into fast wavelength-hopped time-spread waveforms through a wavelength-selective time-delay device. A 1-Gbps digital transmission experiment through a 15-km dispersion-shifted single-mode fiber link is presented. This technique avoids the need for a fast wavelength tunable optical source.

Mendez et al. Demonstrated that 2-D wavelength/time codes have better SE than one- dimensional (1-D) CDMA/WDM combinations (of the same cardinality). Then, the paper described a specific set of wavelength/time codes and their implementation. The 2-D codes have high performance because they simultaneously have high cardinality >>10), per-user high bandwidth (>1Gbps), and high SE (>0.10 b/s/Hz). The physical implementation of these W/T codes is described and their performance evaluated by system simulations and measurements on an OCDMA technology demonstrator. This research shows that OCDMA implementation complexity (e.g., incorporating double hard-limiting and interference estimation) can be avoided by using a guard time in the codes and an optical hard limiter in the receiver.

Vincent J. Hernandez et al. [24] described a technology demonstrator for an incoherent optical code-division multiple-access scheme based on wavelength/time codes. The system supports 16 users operating at 1.25 G symbols per user while maintaining bit-error rate (BER) $10^{\wedge 11}$ for the correctly decoded signal. Experiments support previous simulations which show that coherent beat noise, occurring between the signal and multiple access interference, ultimately limits system performance.

Thomas H. Shake [25] examined the degree and types of security that may be provided by OCDMA encoding. A quantitative analysis of data confidentiality is presented for OCDMA encoding techniques. It is shown that increasing code complexity can increase the Signal-to- Noise Ratio (SNR) required for an eavesdropper to “break” the encoding by only a few dB. Rapid reconfiguration of codes can also increase the difficulty of interception. The overall degree of confidentiality obtainable through OCDMA encoding is also compared with that obtainable through standard cryptography.

2.2 MOTIVATION-:

According to the literature survey it has been observed that the type of codes used is a major factor influencing the performance of any OCDMA system. Up till now, various 1-D codes for the OCDMA systems are proposed and compared theoretically but comparison of codes on the basis of data modulation format has been rarely done. The existing 1-D codes are having restrictions on code lengths and weights. Two dimensional codes operate in both time and wavelength domain can be a good solution to the limitations offered by one dimensional codes. Various approaches have been suggested for design of 2-D codes. The wavelength/time codes are here constructed using folded optimum Golomb ruler sequences.

2.3 Objective of the Dissertation-:

The objectives of the dissertation are

- To design the two-dimensional wavelength/time code and their implementation in OCDMA System.

- To analyze the performance of the system in terms of BER, eye diagram under the Influence of simultaneous users with different received power.

CHAPTER 3

CONSTRUCTION OF 2D WAVELENGTH/TIME CODES

In this chapter, two dimensional wavelength/time codes are designed and implemented. The two dimensional (2-D) codes are constructed by a technique based on folding of Golomb rulers. The performance evaluation of OCDMA system based on wavelength/time code has been analyzed by measuring the values of bit error rates and eye diagrams for different number of active users. It is shown that eye opening decreases and BER increases with increase in number of active users. It is also shown that BER further increases with increase number of active users when number of decoders increases on receiver side. Hence, it is concluded that MAI is the dominant source of BER and there is graceful degradation in system performance when number of simultaneously active user's increases. The received optical power is also measured at different transmission distance. It has been observed that optical power is also measured at different transmission distance. It has been observed that received optical power decreases with increase in length of fiber due to attenuation.

3.1 INTRODUCTION-:

As a core of an OCDMA system, various different types of optical codes have been proposed and studied for various OCDMA technologies: one-dimensional (1-D) codes which spread in time [15] or in frequency [28] and two-dimensional (2-D) codes which spread in both time and wavelength [21]. Wavelength-Hopping Time-Spreading (WHTS) system is a 2-D coding approach that spreads the codes in both the time and wavelength domains simultaneously [22]. The general schematic of an OCDMA network is shown in figure 3.1. The two main elements of the transmitter are the source and the encoder while the receiver consists of the decoder and the receiver electronics. In 2-D OCDMA, pulses are placed in different chips across the bit period and each chip is of different wavelength, thus following a wavelength- hopping pattern, achieving increased code design flexibility as well as code performance. Thus, WHTS codes can be represented as code matrices with time and wavelength as its two axes—the wavelength domain is divided into Ni wavelength channels and the time domain is divided into NT chips [29]. In this all active users share the same wavelength and time domain space, providing a fair division of the bandwidth. It provides truly asynchronous access, which in turn greatly simplifies network control and management.

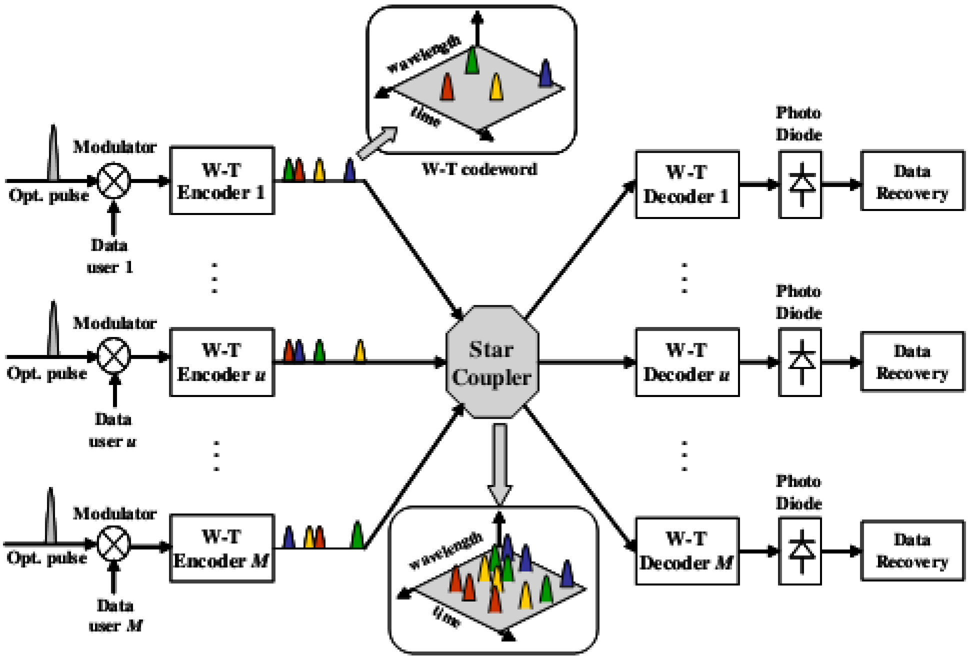


Figure 3.1 Typical Diagram of Wavelength/ Time OCDMA Network

In spite of the use of orthogonal codes, the main effect limiting the effective signal-to-noise ratio of the overall system is the interference resulting from the other users transmitting at the same time, which is called Multiple Access Interference (MAI). MAI is the major source of noise in OCDMA systems [18]. The number of users in a WHTS OCDMA network has a soft limit with a graceful degradation of performance with increasing number of users [29].

Antonio J. Mendez et al. [13] presented a technique for generating PSO matrices from sets of optimum Golomb rulers. It is shown that 2-D codes have higher cardinality and good spectral efficiency, especially when compared to linear or direct sequence code. This paper describes the design and construction of the matrices; analyzes their performance from a communications viewpoint; describes their use as codes for the asynchronous, concurrent communication of multiple users; and analyzes the bit error rate performance based on capturing and modeling a typical network topology and performing a numerical modeling of the system.

S. Yegnanarayanan et al. [21] demonstrated a new technique for implementation of fast wavelength hopping incoherent OCDMA. The output pulse from a mode locked laser is spectrally broadened through super-continuum generation. This pulse is then encoded into fast wavelength-hopped time-spread waveforms through a wavelength-selective time-delay device. A 1-Gb/s digital transmission experiment through a 15-km dispersion-shifted single- mode fiber link is presented. This technique avoids the need for a fast wavelength tunable optical source.

Mendez et al. Demonstrated that 2-D wavelength/time codes have better SE than one dimensional (1-D) CDMA/WDM combinations (of the same cardinality). Then, the paper described a specific set of wavelength/time codes and their implementation. The 2-D codes have high performance because they simultaneously have high cardinality >>10), per-user high bandwidth (>1Gbps), and high SE (>0.10 b/s/Hz). The physical implementation of these W/T codes is described and their performance evaluated by system simulations and measurements on an OCDMA technology demonstrator. This research shows that OCDMA implementation complexity (e.g., incorporating double hard-limiting and interference estimation) can be avoided by using a guard time in the codes and an optical hard limiter in the receiver.

Vincent J. Hernandez et al. [24] described a technology demonstrator for an incoherent optical code-division multiple-access scheme based on wavelength/time codes. The system supports 16 users operating at 1.25 G symbols/s/user while maintaining bit-error rate (BER) $10^{\wedge 11}$ for the correctly decoded signal. Experiments support previous simulations which show that coherent beat noise, occurring between the signal and multiple access interference, ultimately limits system performance.

Up till now, various approaches have been suggested for design of 2-D codes and performance analysis is done for the increase in number of users on the transmitter side only. In this chapter, 2-D matrix codes are constructed using folded Golomb ruler and their performance analysis is done for the increase in number of users at both transmitter and receiver side.

3.2 ANALYTICAL MODEL-:

An (n, w, λ_a, λ_c) optical orthogonal code C is a set of (0, 1) sequences of length n and weight w (the number of ones in every codeword). The size of the code is the number of codeword in C and is called its cardinality. The set is constructed so that it has the following two properties [19].

The Auto-Correlation Property

$$\sum_{t=0}^{t=n-1} x_t x_{t+\tau} \leq \lambda_a$$

For any x Є c and any integer τ, 0 < t < n.

The cross-correlation property

$$\sum_{t=0}^{t=n-1} x_t x_{t+\tau} \leq \lambda_c$$

For any x # y Є c and any integer τ.

τ_a is the auto correlation and τ_c is the cross correlation constraints.

The autocorrelation of each sequence in the optical orthogonal code exhibits the thumbtack shape and the cross correlation between any two sequences remains low throughout[19]. Since each sequences x has the weight w, the auto correlation equals w when τ = 0. Thumbtack-shaped auto-correlation enables the effective detection of the desired signal and low-profiled cross-correlation makes it easy to reduce interference due to other users and channel noise.

3.3 CONSTRUCTION OF 2-D MATRIX CODES-:

A technique based on the “folding” of spanning rulers or optimum Golomb rulers [30] to generate pseudo orthogonal matrix codes is explained is given below.

A spanning ruler or optimum Golomb ruler is a (0, 1) pulse sequence where the distances between any of the pulses is a non-repeating integer. The optimum Golomb ruler g(1,7) of cardinality 1, weight 7, and length 26 [31] is shown at the top of figure 4.2. After that a table is shown contains the ruler and three shifted versions (all in bold) of the ruler. To make up the code dimension (CD) of 32 filter zeros are used in table.

g (1,7) =

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

	Column (C1)				Column (C2)				Column (C3)				Column (C4)				Column (C5)				Column (C6)				Column (C7)				Column (C8)			
	r_1	r_2	r_3	r_4	r_1	r_2	r_3	r_4	r_1	r_2	r_3	r_4	r_1	r_2	r_3	r_4	r_1	r_2	r_3	r_4	r_1	r_2	r_3	r_4	r_1	r_2	r_3	r_4	r_1	r_2	r_3	r_4
M1	1	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0
M2	0	1	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0
M3	0	0	1	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0
M4	0	0	0	1	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0

Mi from g (1,7)

M1

	c1	c2	c3	c4	c5	c6	c7	c8
r1	1	1	0	0	0	0	0	0
r2	1	0	0	0	0	0	1	0
r3	0	0	1	0	1	0	0	0
r4	0	0	0	0	0	1	0	0

M2

	c1	c2	c3	c4	c5	c6	c7	c8
r1	0	0	0	0	0	0	1	0
r2	1	1	0	0	0	0	0	0
r3	1	0	0	0	0	0	1	0
r4	0	0	1	0	1	0	0	0

M3

	c1	c2	c3	c4	c5	c6	c7	c8
r1	0	0	0	1	0	1	0	0
r2	0	0	0	0	0	0	1	0
r3	1	1	0	0	0	0	0	0
r4	1	0	0	0	0	0	1	0

M4

	c1	c2	c3	c4	c5	c6	c7	c8
r1	0	1	0	0	0	0	0	1
r2	0	0	0	1	0	1	0	0
r3	0	0	0	0	0	0	1	0
r4	1	1	0	0	0	0	0	0

Figure 3.2: Construction the four pseudo-orthogonal (PSO) matrices M1, M2, M3, M4 from the single optimum golomb ruler g (1, 7)

The CD is determined as follows [3]: The Golomb rulers are shifted as shown in figure2 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; hence the number of new matrices depends on the two parameters. One 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.

$$r * C - L \geq r - 1$$

During the design process, chose the dimension “r” first and it’s should be a multiple of two because of optical component (e.g., coupler or WDM multiplexer/ demultiplexer) characteristics.

Returning to figure 3.2 given L = 26 and assuming r = 4 and trials C=7,8. When C=7, then r * c =4 * 7 = 28 gives M = 28 -26 +1 = 3 and for C = 8, r * c = 4 * 8 = 32 gives M =31 – 26 -1 =7. Out of 7,4 shifts produce new OOC matrices and remaining three shifts that do not produce OOC matrices due to cyclic nature of operation. Hence the value of M is taken as 4. Increasing the CD be increasing the number of columns does not increase due to cyclic nature of shifting process. Thus with r = 4,32 is the optimum CD with C = 8, Maximizing both the matrix code set size M.

The headings in Mi of figure 3.2 define the column and row to which the table entries should be transposed. Take the transpose of column 1 of Mi to make the C1 of matrix M1. Similarly transpose the column 2 of Mi to make C2 of matrix M1 and so on. The un-shifted ruler, with column/row algorithm, defines the new matrix M1; the shifted rulers, define M2-M4; these are shown at the bottom of the figure. The resulting matrices are optical orthogonal codes.

g1 (4, 4)

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

g2 (4, 4)

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

g 3(4, 4)

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

g4 (4, 4)

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

Mi from g1 (4, 4)

	Column 1 (C1)								Column 2 (C2)								Column 3 (C3)								Column 4 (C4)							
	r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8	r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8	r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8	r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8
M1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
M2	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0
M3	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
M4	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0
M5	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
M6	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0
M7	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
M8	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1

Figure 3.3: Constructing 32 PSO matrices M1.M2…..M32 with eight rows and four columns from set of four optimum Golomb rulers g1 (4, 4) g4 (4, 4)

The ruler-to-matrix transformation [23] enhances cardinality (code set size) and while preserving the OOC property. This transformation increases the cardinality (n versus n*r) from one (1) to four (4).

The concept of folded optimum Golomb rulers is 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 [31] is shown in the upper portion of figure 3.3. The ruler g1(4,4) thus generates the matrix M1, g2(4,4) generates M9; g3(4,4) generates M17 , and g4(4,4) generates M25 [33]. Cyclic row shifting allows M1 to produce M1…M8; M9 produces M10…M16; M17 produces M18…M24 and M25 produces M26…M32. The eight shifted versions of g1(4,4) are shown in bottom portion of figure 3.3. Now same method is used with these shifted versions as in the previous example to generate the eight OOC matrices of figure 3.4

M1			
1	1	0	1
0	0	0	0
0	0	1	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

M2			
0	0	0	0
0	0	0	0
1	1	0	1
0	0	0	0
0	0	1	0
0	0	0	0
0	0	0	0
0	0	0	0

M3			
0	0	0	0
0	0	0	0
1	1	0	1
0	0	0	0
0	0	1	0
0	0	0	0
0	0	0	0
0	0	0	0

M4			
0	0	0	0
0	0	0	0
0	0	0	0
1	1	0	1
0	0	0	0
0	0	1	0
0	0	0	0
0	0	0	0

M5			
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
1	1	0	1
0	0	0	0
0	0	1	0
0	0	0	0

M6			
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
1	1	0	1
0	0	0	0
0	0	1	0

M7			
0	0	0	1
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
1	1	0	1
0	0	0	0

M8			
0	0	0	0
0	0	0	1
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
1	1	0	1

Figure 3.4: The eight OOC matrices M1 ……….M8 genrated from the optimum golomb ruler g1 (4, 4)

The initial set of four optimum Golomb rulers folded into eight-row matrices produces 32 OOC matrices based on the ruler-to-matrix construction. It should be noted that the cardinality goes from four to 32.

Table 3.1: The 32 PSO Matrix Codes Interpreted as W/T Matrix Codes

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

The PSO matrices are converted to wavelength/time (W/T) codes by associating the rows of the PSO matrices with wavelength (or frequency) and the columns with time-slots, as shown in Table 3.1. The matrices M1… M32 are numbered 1… 32 in the table, with the corresponding assignment of wavelengths and time-slots. The codes M1 and M9 are shown bold in table. The code M1 is represented as ($\lambda1$; $\lambda1$; $\lambda3$; $\lambda1$) and M9 as ($\lambda1$, $\lambda4$; 0; $\lambda7$, $\lambda8$; 0); here the semicolons separate the timeslots in the code. In code M9 there are two wavelengths ($\lambda1$, $\lambda4$) 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. It is the extensive wavelength and time-slot reuse that gives these matrix codes their high cardinality.

CHAPTER 4

SYSTEM DESIGN & IMPLEMENTATION

4.1 Introduction-:

The following two sequences from optimal Golomb ruler with Length L = 18 and weight, W = 6 are used for the system design.

1. Sequence 1 { 1,1,0,0,1,0,0,0,0,0,1,0,1,0,0,0,0,1}
2. Sequence 2 { 1,0,0,1,0,1,0,0,0,1,0,0,0,0,0,0,1,1}

These sequences are used as baseline to design Wavelength/ Time codes. These two sequences are taken as one-dimensional superimposed cyclic code, which is then converted to two-dimensional superimposed codes using ruler to matrix transformation. The dimension of the matrix has been decided for the conditions i.e. $(W \times T) \geq L$ where W is the number of Wavelength and T is the number of Time slots.

With w = 3 and T = 6, a (3 × 6) physical matrix can be formed without any need of filler zero's. This is a compact and optimum size because it satisfies $(W \times T) \geq L$ i.e. as $W \times T = 18$ which is equal to L, i.e. 18 and requires less, i.e. 3 lasers for one codeword. So this is more optimum situation because it saves the cost of the laser by increasing one more optical delay line.

Table 4.1.1 and 4.1.2 represent the code C1 C2 respectively. So in this coding technique total six mode locked lasers of Wavelengths (W1, W2, W3, W4, W5 and W6) are used to design thirty-six codes.

Table 4.1.1 W/T code 1

C1	T_0	T_1	T_2	T_3	T4	T_5
W4	1	0	0	0	0	0
W5	1	0	0	0	1	0
W6	1	1	0	1	0	0

Table 4.1.2 W/T code 2

C2	T_0	T_1	T_2	T_3	T4	T_5
W1	1	1	0	1	0	0
W2	0	0	0	0	0	1
W3	0	1	0	0	0	1

The system is designed by using six mode locked lasers of different wavelength ranging from $1550e^{-9}$ m to $1.554e^{-6}$ m with $0.7e\text{-}^{9}$ m wavelength spacing which generates the pulse of width e^{-11} which is equal to data rate of the system i.e. $1e^{9}$ for 1 Gbps system. Figure 4.1.1 describes the architecture of the OCDMA system using the new encoder structure.

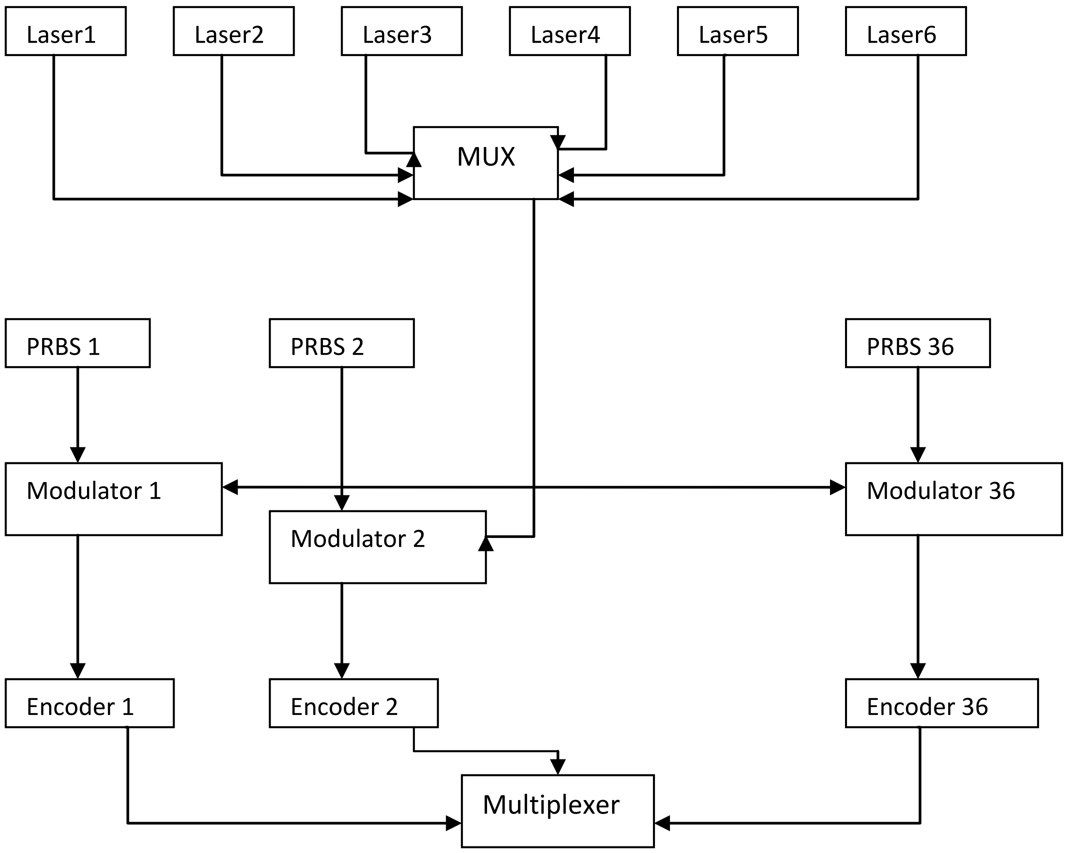


Figure 4.1.1 Optical CDMA system design using W/T codes

The pseudo random sequences are used as a data source of $2^6 – 1$ pattern length. The Machzender modulator Linbo3 modulator modulates this data signal with the carrier, which is then fed to the encoder. The encoder of code 1 is designed by using optical filter and time delay circuits of three wavelengths and 6 time slots as represented in figure 4.1.2.

In this system, 36 codes have been designed for different wavelength and time delay combinations. The bit period and chip period of 1Gbps system is $1e^{-9}$ s and $1.67e^{-10}$ s respectively. Table 4.1.3 represents the chip period and time-delay of the various time slots.

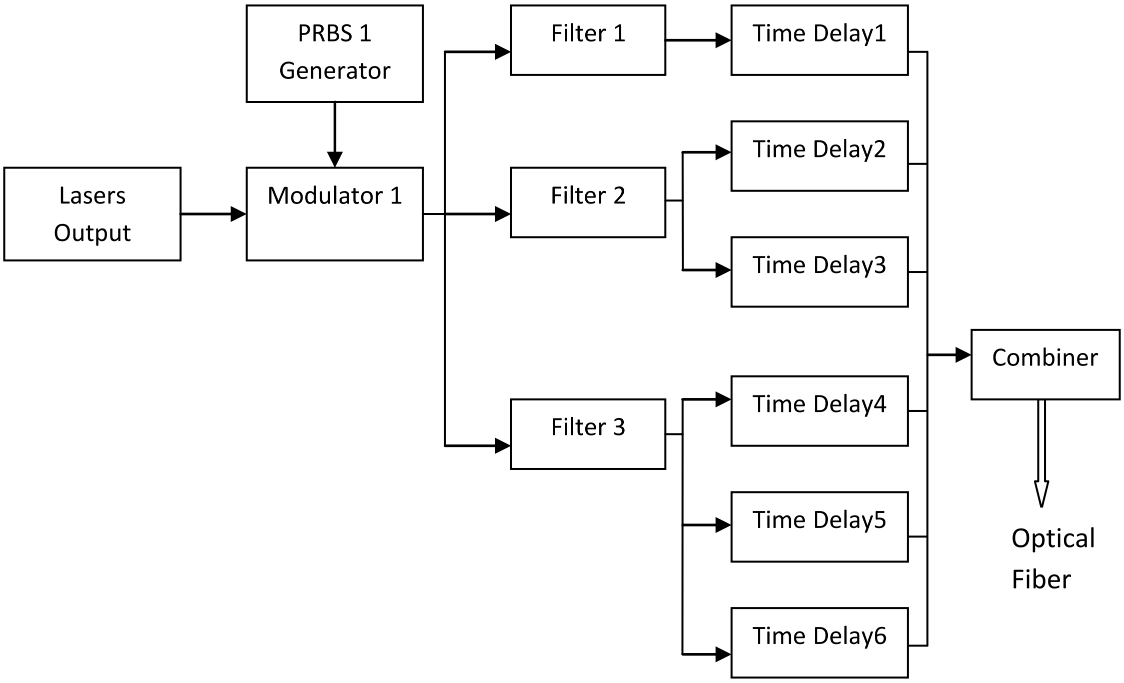


Figure 4.1.2 Encoder Design of optical CDMA system

Table 4.1.3 Time Delay for 1Gbps system for Various Time Slot

Time Slots	Chip Period for 1Gbps System (s)	Time delay for 1Gbps System (s)
0	$1.67e^{-10}$s	0 s
1	$1.67e^{-10}$s	$1.67e^{-10}$s
2	$1.67e^{-10}$s	$3.34e^{-10}$s
3	$1.67e^{-10}$s	$5.01e^{-10}$s
4	$1.67e^{-10}$s	$6.68e^{-10}$s
5	$1.67e^{-10}$s	$8.35e^{-10}$s

In the encoder the corresponding wavelength according to the codes are filtered out and time delays places the pulses in their appropriate time slots which are further combined with the help of combiner. These encoded codes from all the users are then multiplexed and passed through the 40 km span of the single mode fibre followed by a loss compensating EDFA amplifier.

4.2 Implementation of the system using Optsim software:

The simulation setup using optsim simulation software for Transmitter1 of OCDMA system is shown in figure 4.2.1. Here we have demonstrated an incoherent OCDMA system based on a wavelength-time spreading coding technique. The 2 – D W/T code has been redesigned by using three wavelength and six time slot in the system. Six mode locked laser have been used to create a WDM multi-frequency light source i.e. carrier signal using optMUX1. This carrier signal is used to modulate the PRBS data of the user. After modulation an encoder is used for encoding the signal. Mode locked laser is used for generating pulses of pulse width of e^{-11} at repetition rate equal to data rate of the system. The wavelength range from 1550 nm to1554 nm, with 0.7 nm wavelength spacing.

The PRBS data generator is used to generate random data of 26-pattern length. An electrical NRZ signal generator is used to convert digital data into electrical signal. A Mach-Zehnder LiNbO3 modulator modulates the multiplexed 6 wavelengths according to the NRZ electrical data.

The modulated signals are distributed to the respective encoders, which have been assigned a unique W/T code respective to each encoder. In an encoder three optical filters and six shift signals are used to produce the encoded bit stream. The optFil is used to filter out one spectral wavelength and then the shiftSig is used to produce a pulse at specified chip. The encoder used delay line arrays providing delays in terms of integer multiples of chip times. The placement of the delay lines arrays and the amount of each delay are dictated by the specifies of the user signatures. The combiner combines six of the displaced pulses to from an encoded signal. The encoded data from all users are multiplexed and then pass through 40 km span of fibre followed by a low compensating EDFA amplifier (Amp1). The output signal from fibre span then passed through splitter to split the signal and routed the user's decoder. The decoder tuned to the same structure as the corresponding encoder but with negative delays as compared to encoder, providing delays in terms of integer multiples of chip times. The decoded signal finally arrives at optical receiver.

The eye diagram analyzer has been used to take the plot of eye diagram. Bit error rate values for different received power have been taken from BER tester. The system has been redesigned for 36 different users as shown in simulation step in figure 4.2.2.

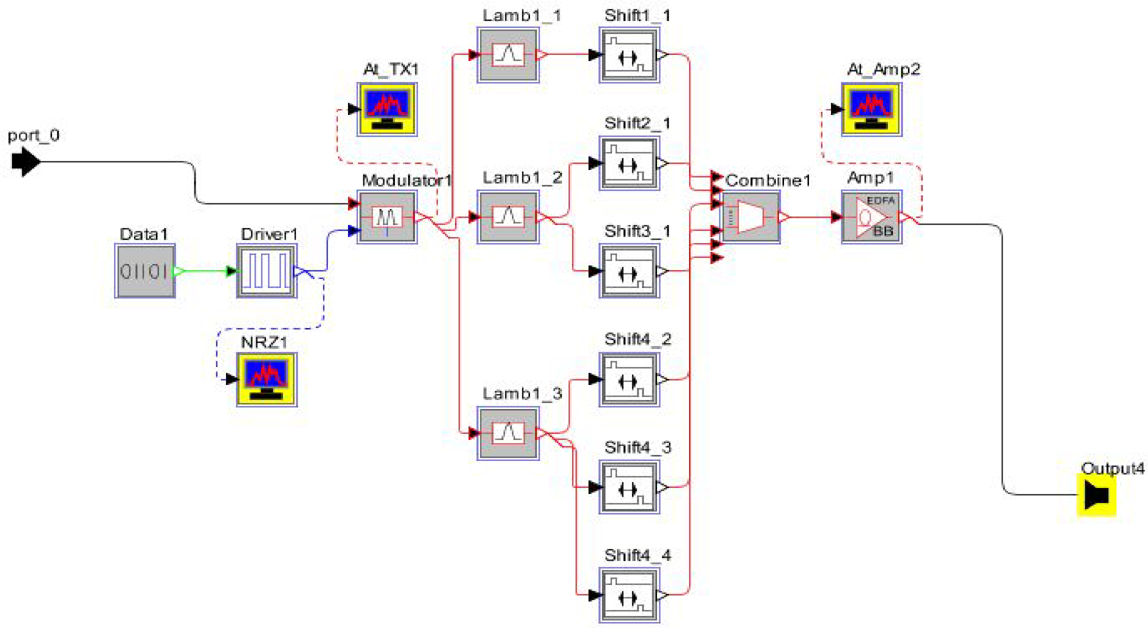


Figure 4.2.1: Encoder for one user

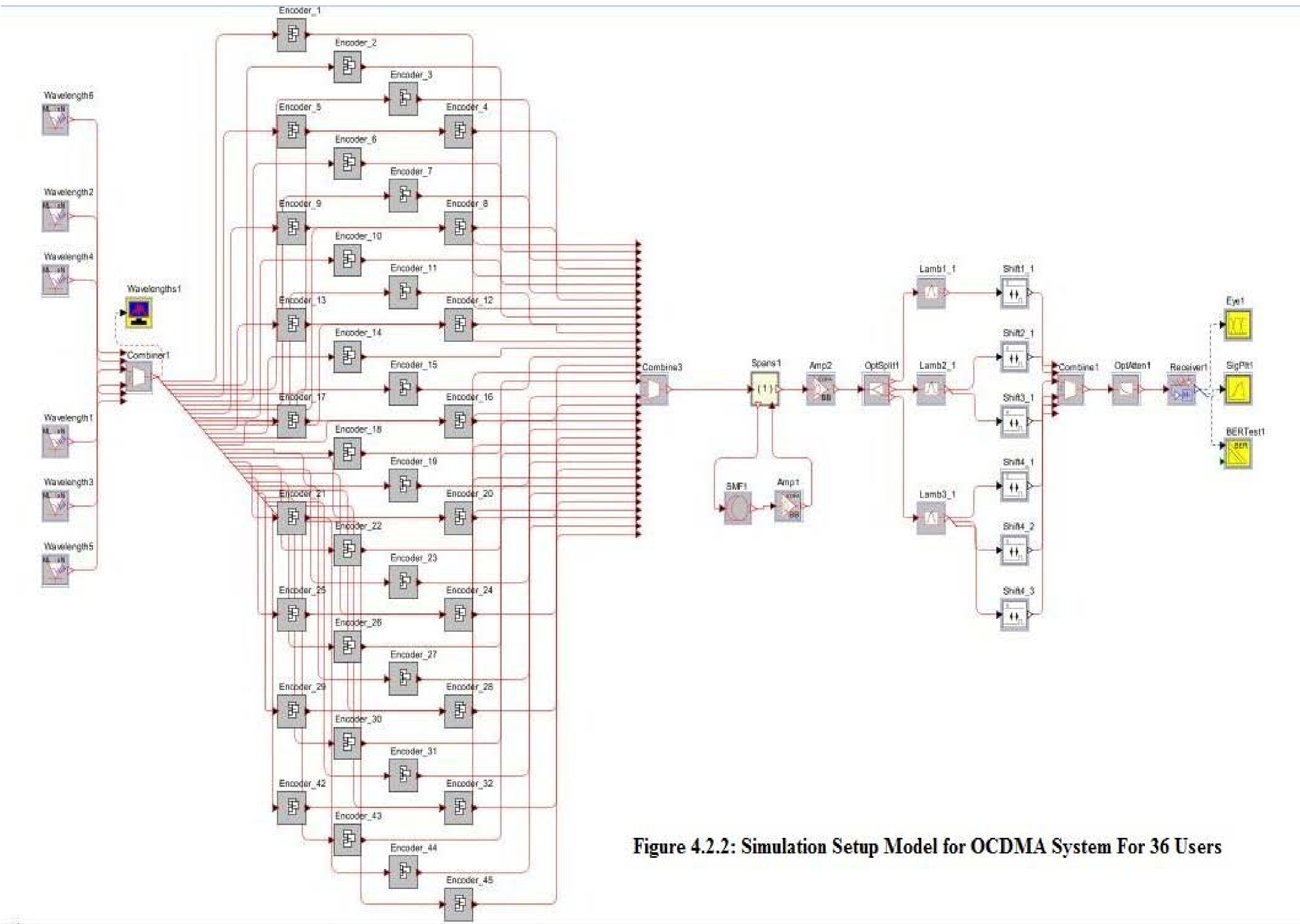
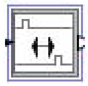
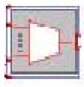
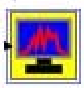
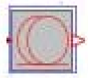
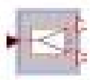
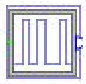
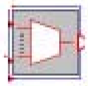
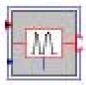
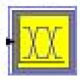
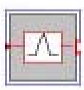


Figure 4.2.2: Simulation Setup Model for OCDMA System For 36 Users

4.3 Description of components used in OCDMA System Design:

The OCDMA system has been designed with OPTSIM simulation software using various components. Table 4.3 represent the various symbols used for these components.

Table 4.3: Symbol Used for System Design

S.No	Symbol	Name of the component	S.No	Name of the component	Symbol
1		Mode Locked Laser	8	Optical shift Signal/Time delay	
2		Combiner	9	EDFA Amplifier	
3		Wavelength1 Multiport	10	Non linear single mode fibre	
4		PRBS Data Generator	11	Optical Splitter	
5		Electrical Signal Generator/ Driver	12	Optical Multiplexer	
6		Modulator	13	Eye diagram Analyzer	
7		Optical Fibre	14	Bit error rate Tester	

4.3.1 Mode Locked Laser:

They are used for generation of optical beam. They can support pulse type of Gaussian, Sech and super Gaussian. In this design Sech pulses have been selected because pulse are very sharp as compared to the Gaussian pulses.

The pulse shape of Gaussian pulse is

$$u(t) = \exp\{-0.5(t_0/T_0)^2\}$$

And the pulse shape of the Sech pulse is

$$u(t) = \mathrm{sech}(t_0/T_0)$$

In this design, the laser source is characterized by its power, wavelength, line width and phase. The parameter used for mode locked laser are represented in table 4.3.1

Table 4.3.1: Parameter Description of Mode Locked Laser

Mode Locked Laser		
Parameter	Description	Designed system parameters
Type	Mode locked source type Guassion,Super Guassian, Sech	Sech
Repetition Rate	Repetition Rate of the source	$1e^9$ for 1 Gbps system $2.5\ e^9$ for 2.5 Gbps system
Pattern Length	Bit pattern length =2x, where x is input	6
Points Per Bit	No. of sampling points per bit period in output optical signal	8
Peak Power	Peak Power	0.003 W
Wavelength	Wavelength of the laser	$1.55e^{-5}$m
Delta	Difference of all wavelengths	$0.7e^{-9}$m
N	No. of lasers	06

4.3.2: Combiner-:

The combiner represents an optical WDM optical signal at its input ports and produces a WDM optical signal as its output port. Basically, the combiner is a ‘6 × 1’ optical multiplexer with one output. An assumption of 3db loss is incorporated in the combiner. The output from this combiner can be seen through the Multipot attached at the output of combiner.

4.3.3 PRBS Pattern Generator-:

The PRBS pattern generator generates a binary sequence of several different types. This single component may be used to provide multiple pattern output to drive different channel of a WDM or parallel optical bus simulation. There are options of all ones, all zeros, PRBS data generator and users defined data output. In users defined data each channel may have its own model instance configured to provide a different pattern than the other model instances. In this research PRBS pattern has been chosen because this data pattern is more equivalent to the data used by any user, The Parameters of PRBS data generator are tabulated in table 4.3.2.

Table 4.3.2 Parameters description of PRBS Data Generator

PRBS Data Genrator		
Parameter	Description	Designed system parameters
Pattern Type	The type of pattern to be genrated	PRBS
Bit Rate	The bit rate of binary sequence is generated	$1e^9$ for 1 Gbps system $2.5\ e^9$ for 2.5 Gbps system
Pattern Length	The number of bits in the generated bit sequence is 2x where x is the parameter value.	6 (2^6 x bits)
Pre Bits	The number of zero bits at the start of the sequence	2 bits
Post Bits	The number of zero bits at the end of the sequence	3 bits

4.3.4 Driver-:

The driver converts an input binary signal into an output electrical signal. The output signal may be specified as either voltage or current. The user parameters are used to configure the electrical signal output. Three different modulation formats are also available. These are NRZ i.e. non-return to zero format, the RZ, i.e. return to zero format and Manchester format. Although the RZ format has been widely employed in long haul fibre transmission systems, as it has a higher tolerance for important impairments caused by fibre transmission effects, the NRZ format is more spectrally efficient and can be used in local and metro access networks where spectral efficiency is important. In this setup NRZ format is used where binary 1 is represented by voltage of 1 V and 0 by no voltage.

4.3.5 Modulator-:

The modulator used here is an electro-optic-modulator. Several type of modulators may be modelled with this block, including the Mach-Zehnder type. When using the modulators model with the mode locked laser model, It must be insured that the number of samples per bit and the bit sequence pattern width for both the binary sequence generator and the mode locked laser model are the same. The output from modulator in the form of signal diagram, eye diagram is shown in next section of this chapter.

4.3.6 Filter-:

In this setup Gaussian filter is used to filter the optical signal amplitude. The user specifies the 3 dB bandwidth in the wavelength domain, and the order of the filter. The bandwidth of this filter is chosen according to the pulse width. The parameter of optical filter are described in the table 4.3.3

Table 4.3.3 Parameter Description of Filter

Filter		
Parameter	Description	Designed system parameters
Wavelength	Optical filter centre wavelength	PRBS
BW	3 dB filter bandwidth in wave length	6 (2^6 x bits)
Loss	Optical Filter insertion Loss	2 bits
Order	Order of Gaussian or Lorentzian Optical filter	3 bits

4.3.7 Optical Time Shift Delay-:

The optical time shift delay is the main part of encoder which can be used to do one of two primary functions delay the output signal relative to the input signal, or shift the signal data around in the data structure's array without modifying the signal timing. Time delay function is used in the system which delays the output signal relative to the input signal by a specified amount by adjusting the start time of the signal while leaving the signal data array alone.

Time delay for 1Gbps, 2.5Gbps, and 5Gbps can be calculated as follows.

For 1Gbps system the bit rate of the individual user is 1Gbps. So bit period can be calculated as

$$bitperiod = \frac{1}{bitrate} = \frac{1}{1 \times 10^9} = 1.0\ e^{-9}s$$

The chip period is the ratio of bit period to the time slots. As the system has 7 time slots, the chip period can be defined as under

$$Chip\ period = \frac{Bitperiod}{Timeslot} = 1.43e^{-10}s$$

Similarly the bit period and chip period of 2.5Gbps and 5Gbps system can be calculated. For 2.5Gbps system the bit period and chip period is $4.0e^{-10}$ s and $5.72e^{-11}$ s respectively where as 5Gbps it is $2.00e^{-10}$ and $2.86e^{-11}$ s respectively.

Table 4.3.4 represent the time delay at different time slots for 1Gbps, 2.5Gbps and 5Gbps system. Practically, the fibre tapped delay lines are designed by using short pieces of standard single mode fibres, in which signal will propagate as desired. The length of these pieces will adjust according to delay the pulse needs to experience.

Table 4.3.4 Time Delay For Various System

Time Slot	Chip Period for 1 Gbps	Time delay for 1 Gbps	Chip Period for 2.5 Gbps	Time delay for 2.5 Gbps	Chip Period for 5 Gbps	Time delay for 5 Gbps
0	$1.43e^{-10}$s	0s	$5.71e^{-11}$s	0s	$2.86e^{-11}$s	0s
1	$1.43e^{-10}$s	$1.43e^{-10}$s	$5.71e^{-11}$s	$5.71e^{-11}$s	$2.86e^{-11}$s	$2.86e^{-11}$s
2	$1.43e^{-10}$s	$2.86e^{-10}$s	$5.71e^{-11}$s	$1.14e^{-10}$s	$2.86e^{-11}$s	$5.72e^{-11}$s
3	$1.43e^{-10}$s	$4.29\ e^{-10}$s	$5.71e^{-11}$s	$1.72e^{-10}$s	$2.86e^{-11}$s	$8.58e^{-11}$s
4	$1.43e^{-10}$s	$5.72\ e^{-10}$s	$5.71e^{-11}$s	$2.29e^{-10}$s	$2.86e^{-11}$s	$1.14e^{-10}$s
5	$1.43e^{-10}$s	$7.14\ e^{-10}$s	$5.71e^{-11}$s	$2.86e^{-10}$s	$2.86e^{-11}$s	$1.43e^{-10}$s

4.3.8 EDFA Amplifier-:

The Erdium Doped Fibre Amplifier (EDFA) is used to amplify the signal at different level of the system. There are two type of optical amplifier gain models in the black box model the defined model and the custom model. There are also several types of optical amplifier noise models the uniform model, the Gaussian model, and the custom model. User defined gain model is used in the setup. In the user defined gain model, the gain variations with wavelength of an optical amplifier are not included. This is partially because the gain flatness depends on the level of saturation of the amplifier and this causes added complexities to the model. The gain flatness will be a significant factor when WDM system are modelled. The gain saturation at high input power is included in this model, with the power gain specified as,

$$G = \frac{G_0}{1 + G_0\left(\frac{P_{ave}}{P_{sat}}\right)}$$

Where G_0 (gain) is the small signal power, P_{sat} is the saturation output power and P_{ave} is the total average power in the fibre. The parameter of EDFA amplifier are described in table 4.3.5

Table 4.3.5 Parameter description of EDFA Amplifier

EDFA Amplifier		
Parameter	Description	Designed system parameters
Gain	Optical amplifier small signal amplitude gain (defined only)	30dB
Psat	Optical amplifier saturation power (defined only)	18dbm
Fn	Noise figure of amplifier	4dB
BW	Optical amplifier ASE noise bandwidth (defined only)	$3.0e^{-8}$m
Noise centre	Optical amplifier ASE noise spectra centre wavelength (defined only)	$1.55e^{-6}$m

4.3.9 Optical fibre-:

A single mode optical fibre can support transmission capacity in the range of terabits per second. This system is specially designed for metropolitan area network by using fibre span 40 km. A single mode graded indexed fibre with core diameter of $8.2e^{-6}$ m is used. A constant fibre attenuation parameter of 0.25dB/km is incorporated to create a realistic environment. The channel also takes into account attenuation, dispersion, Polarization Mode Dispersion (PMD) and non-linearity including Raman effects.

4.3.10 Optical Splitter-:

The optical splitter takes a single input signal and divides it equally among N output ports with 1/N splitting loss.

4.3.11 Optical power normaliser /Optical Attenuator-:

The optical power normaliser normalizes the optical signal power by attenuating the input optical signal to the specified average output power level. This component is used to control the input optical power at the receiver when preparing a BER vs. Received optical power curve plot. This is used to attenuate all input optical signal to the same average output power regardless of their different average input power, or it may be used to attenuate all input signal by the same amount such that the signal with the largest average input power has the specified average output power. Although different researches present the performance by normalizing received power ranging from -8dB to -15 dB but in the set up less power range has been used for performance evolution i.e. 015dB to -30 dB. All the three 1Gbps, 2.5Gbps and 5Gbps system are examined by normalizing received power of values -15dB, -18dB, -20dB, -25dB,-28dB. So the research not only claims to support large no of users then the previous researches but gives better performance even at minimum received power.

4.3.12 Compound Optical receiver-:

The photo-receiver used at the output is composed to several individual building blocks the photo detector, the preamplifier, and the post amplifier/filter complex. Each block is a separate entity complete with its own input parameters and options. The photo-detector model converts an optical input signal to an electrical current. This photocurrent is then passed to the preamplifier model contains a set of baseband filters that shape the output waveforms.

The model also computes the photo receiver noise components. In fact the receiver model is implemented directly in terms of three stand-alone models the PIN/APD photo detector, Electrical amplifier and Electrical Filter model and all the parameter of each of these models are also parameters of monolithic receiver model for both the photo detector and electrical amplifier model a number of noise sources – short noise, dark current noise, signal spontaneous emission beta noise, thermal noise in the pre – amp transistor etc.also included.

4.3.13 Eye Diagram Analyzer-:

The eye diagram is useful tool for the qualitative analysis of signal used in digital transmission. It provides at a glance evaluation of system performance and can offer insight into the nature of channel imperfections. Careful analysis of this visual display can give the user a first-order approximation of signal-to-noise, clock timing jitter and skew. By putting all time slots of the synchronized signal one over another, the traces of the signal amplitude build up to a pattern, which resembles the shape of a human eye. Lower traces stem from the transmitted spaces, while the upper traces originate from transmitted marks. It has become common to place two eyes side by side. The larger the untracked area is, the easier is the signal detection and the better the bit error rate ratio.

4.3.14 Bit Error Rate Tester-:

This block computes the Bit Error Rate (BER) for the input electrical signal as well as a number of useful parameters such as the Q factor and electrical eye properties such as the height, width, area and extinction ratio. The BER may be calculated using either a quasi-Analytical or Monte-carlo algorithm depending on the nature of the dominant noise source in the simulation.

The bit error rate of a fibre link is the most important measure of faithfulness of the link in the transporting the binary data from transmitter to receiver. From time to noise , due to signal degradations from dispersions, non linearity and noise, a signal is so distorted that the detector makes a mistake-a binary one or “mark” is recorded where a binary zero or “space” was transmitted. Clearly, If the link to be of any use, the frequency of such errors must be as small as possible. The BER quantifies the rate of errors and is defined as the probability of an error occurring per transported bit. Typical benchmarks for the BER are rates of BER measured directly. A pseudo random bit source modulating the source is also connected the BER testing apparatus, and the binary value of every transmitted bit is compared against the value of the same bit at the receiver.

4.3.15 Signal Analyzer-:

The signal analyzer block is used to display the signal waveforms of a signal at the node connected to its input ports. In addition, the user may choose among several signal representation options the signal may be displayed as its magnitude only, combined magnitude and phase plots with separate y axes, combined optical signal magnitude and frequency chirp plot with separate y axes. Or separate real or imaginary components. By default, an optical signal is displayed in magnitude representation and an electrical signal is displayed in real representation.

4.3.16 Multiplot-:

This model combines the features of all the four of the previous analyzer blocks the signal analyzer, Eye diagram analyzer and the optical auto correlator. Multiplot is thus far more flexible than the other plot blocks. In this setup, Multiplot has been used to see the output after each and every step.

CHAPTER 5

RESULTS & DISCUSSIONS

In this chapter the value of bit error rate, wavelength spectrum, eye diagram, optical power measured with the help of simulation setup are discussed.

The wavelength spectrum for 1Gbps system is depicted in figure 5.1, which is using multiplot. Each code is designed using three wave length as seen in figure 5.2.

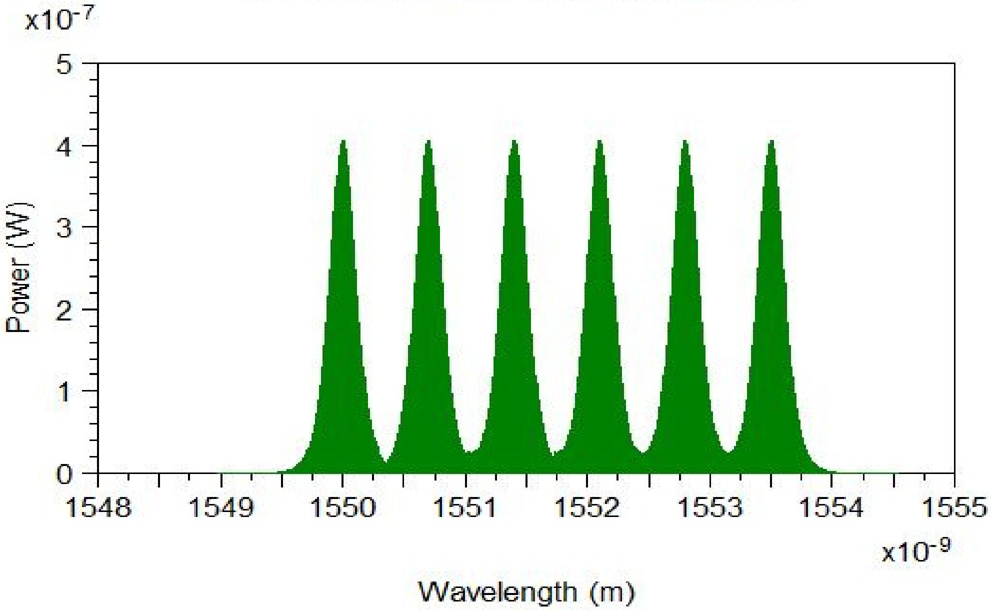


Figure 5.1 Wavelength Spectrums for 1Gbps

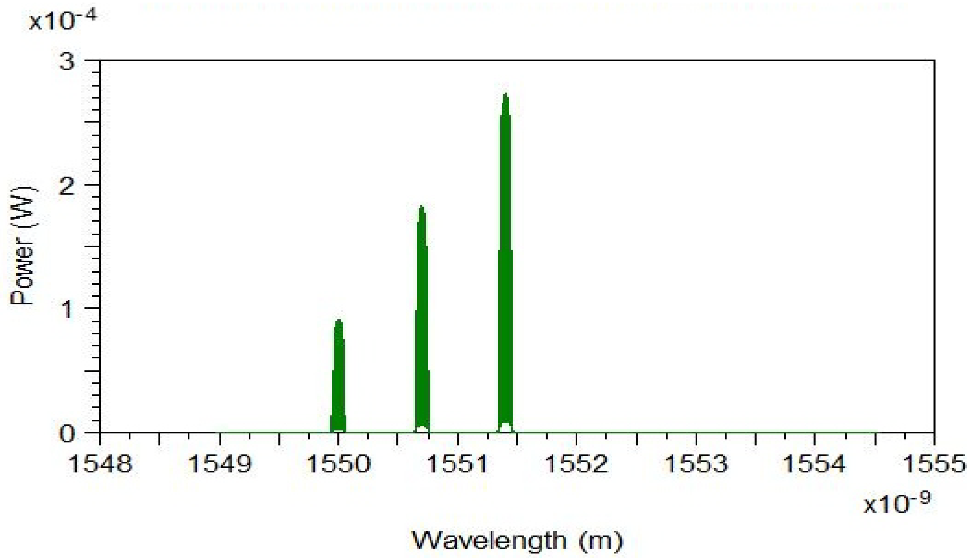


Figure 5.2 Spectrum Analyzer output at encoder

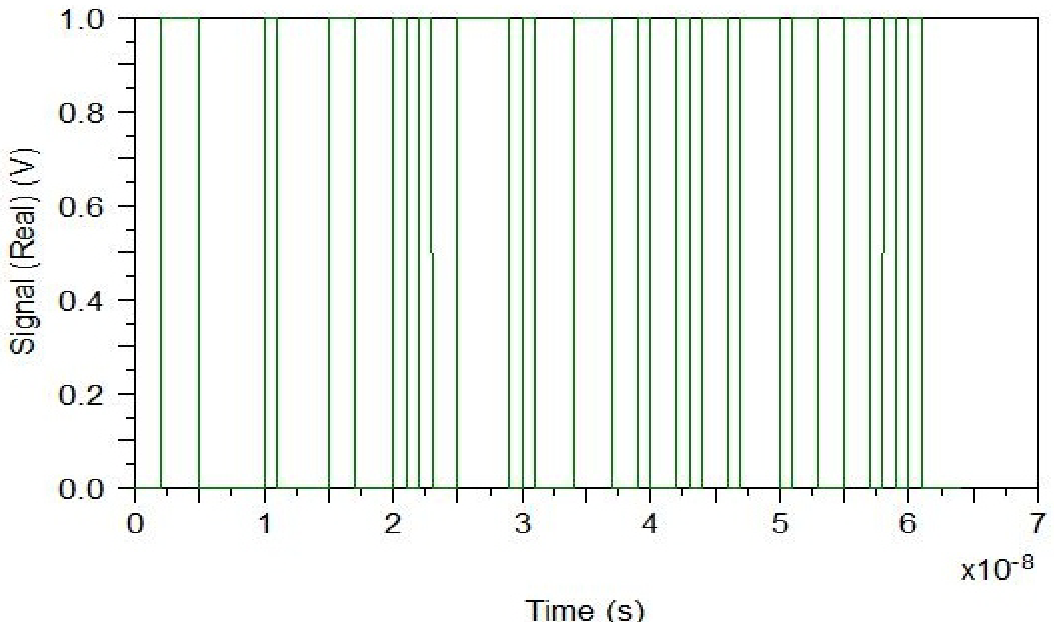


Figure 5.3 NRZ Signal output at for 1Gbps

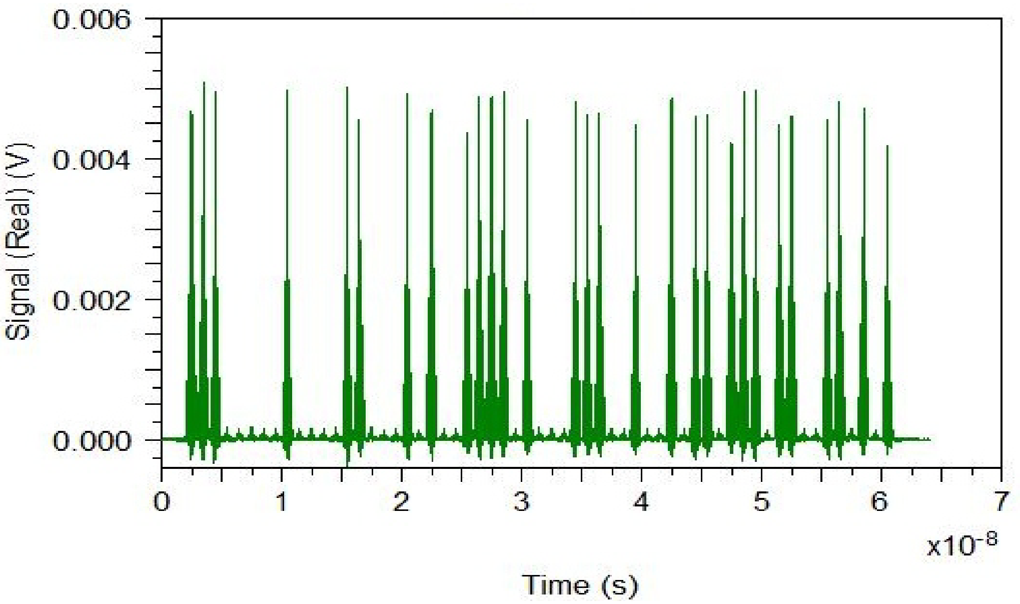


Figure 5.4 Signal Diagram at Receiver for 1Gbps

From Eye diagrams and signal diagrams shown in figure 5.5 to 5.12. It can be analyzed that as the no of users increase from 1 to 5 the multiple access interference increases but it is in acceptable limits. It is further concluded that as the no of users increases from 8 to 16 the signal amplitude starts diminishing. The amplitude of the signal is decreases with increases the no. of users. For 8 users the maximum amplitude of the signal is 0.025V, which degrades for 27 users. It is evident from 5.10 that the multiple access interference exist along with the original signal, which restricts to increase the no. of users.

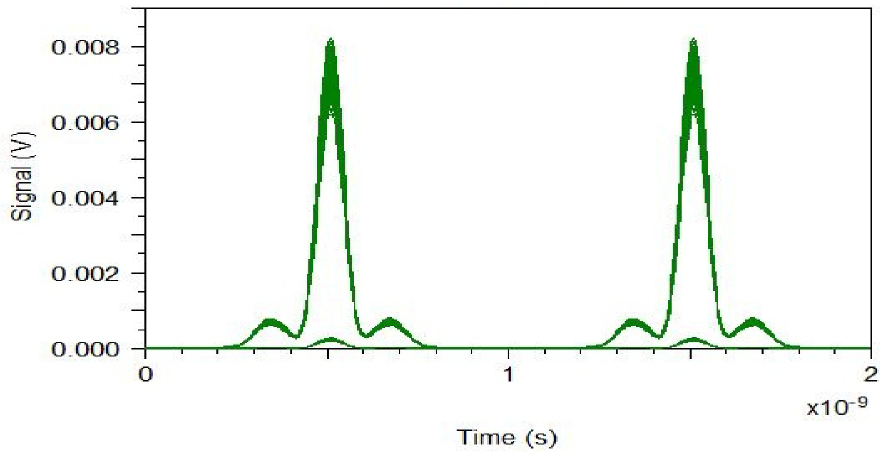


Figure 5.5 Eye diagram for 1 user

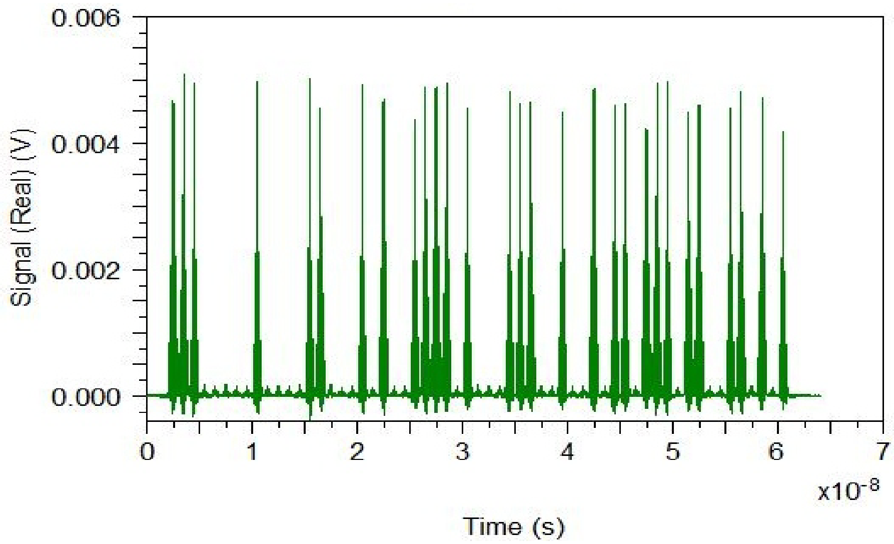


Figure 5.6 Signal Diagram for 1 User

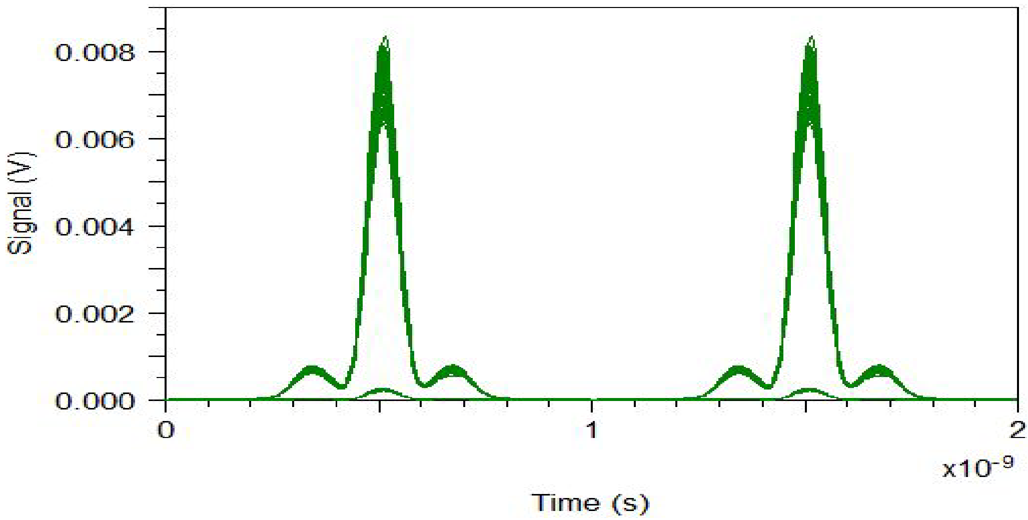


Figure 5.7 Eye Diagram for 2 users

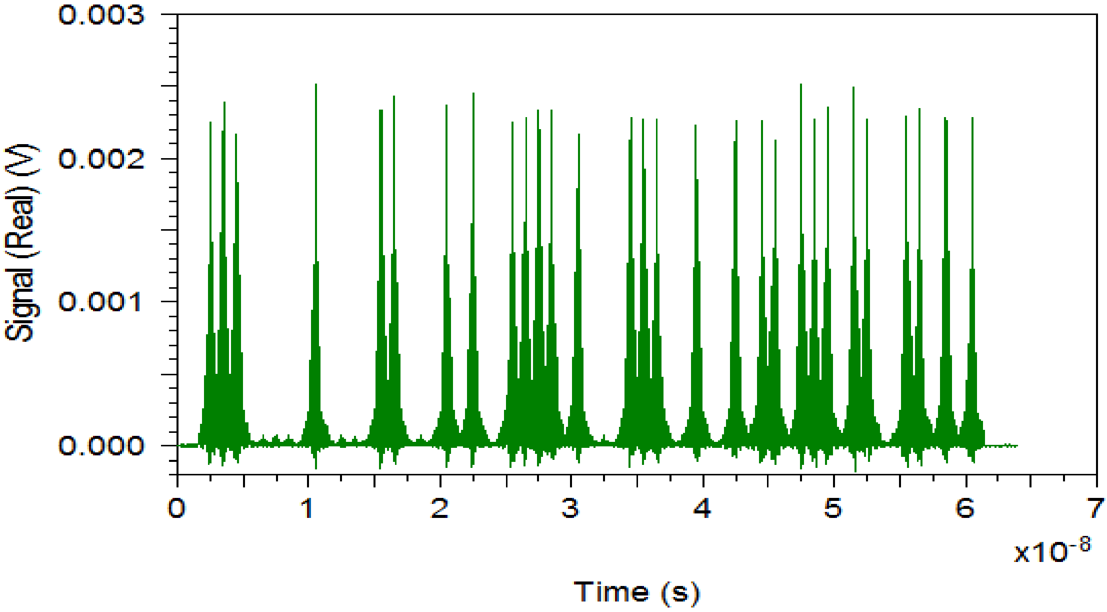


Figure 5.8 Signal Diagram for 8 users

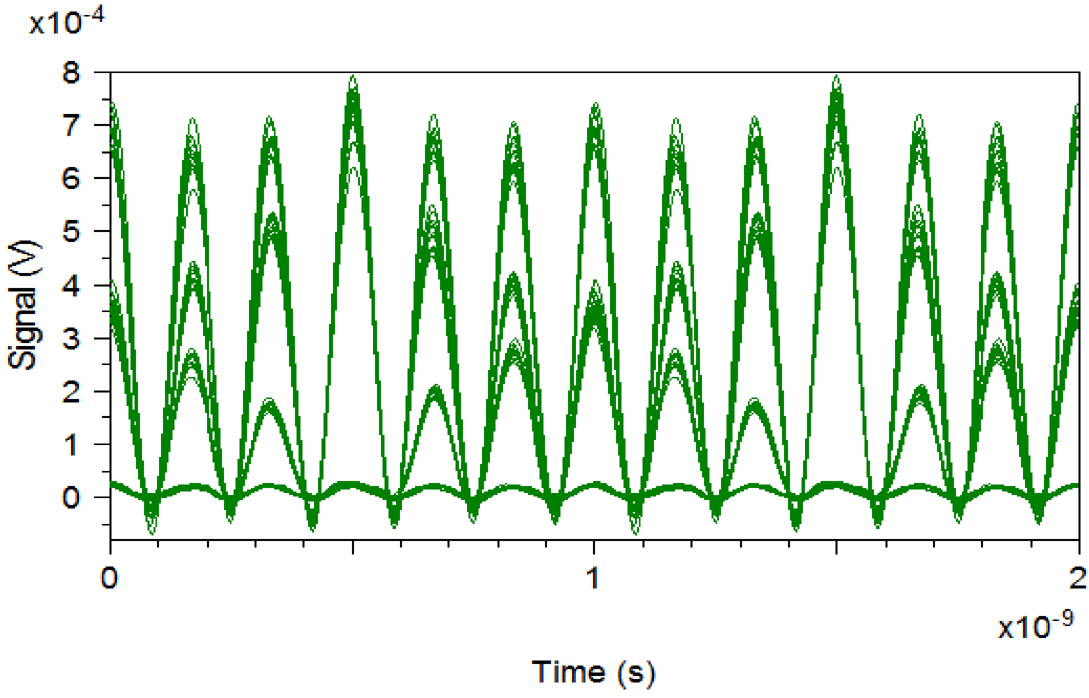


Figure 5.9 Eye Diagram For 16 users

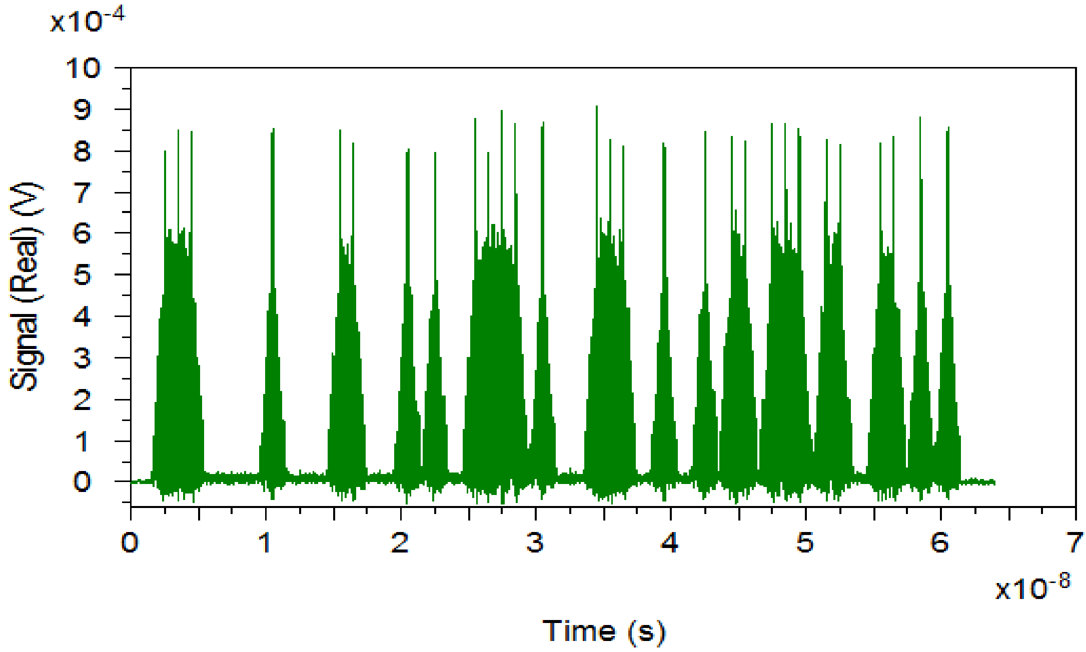


Figure 5.10 Signal Diagram For 16 users

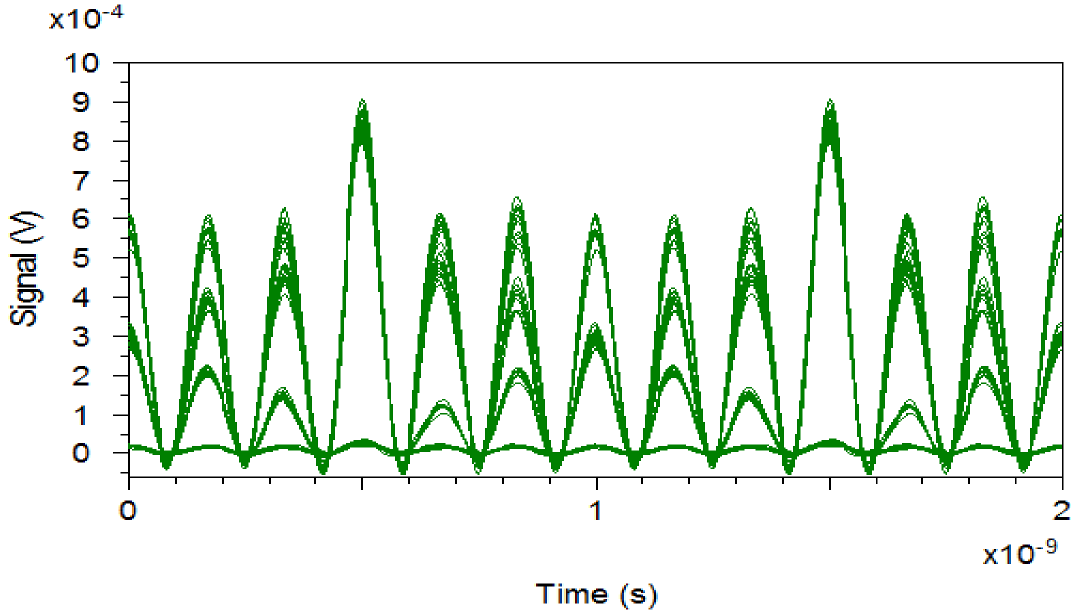


Figure 5.11 Eye Diagram For 27 users

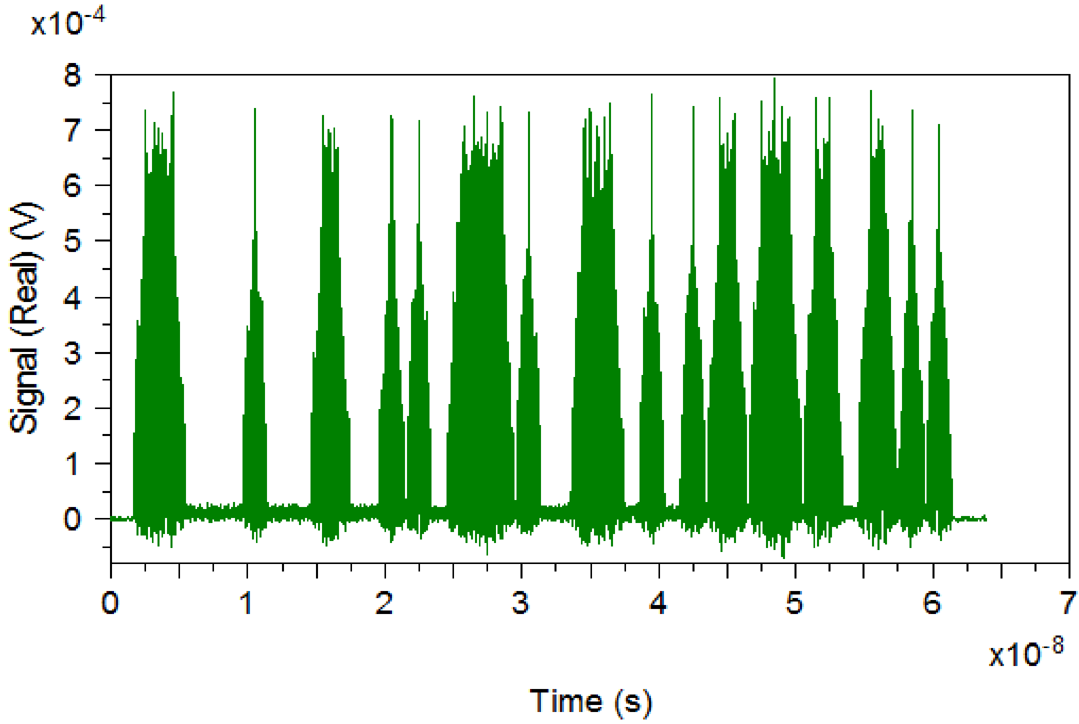


Figure 5.12 Signal Diagram for 27 Users

The Performance of 1Gbps W/T codes based OCDMA system has been evaluated in terms of no. of users and bit error rate at different received power. The permissible bit error rate e-9, This system perform outstanding for -15 db received power and can accommodate 24 simultaneous users for bit error rate of e-9.

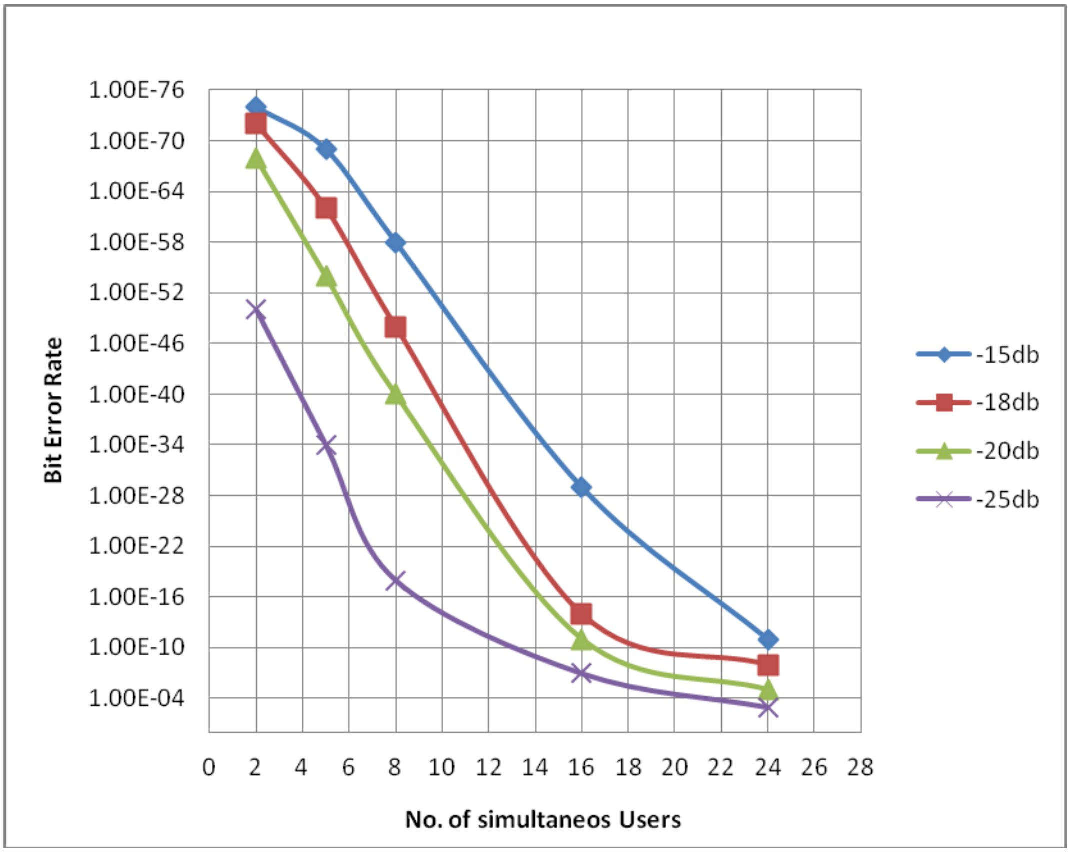


Figure 5.13 Bit error rate versus No. of simultaneous users at different Received power for 1Gbps Based OCDMA System

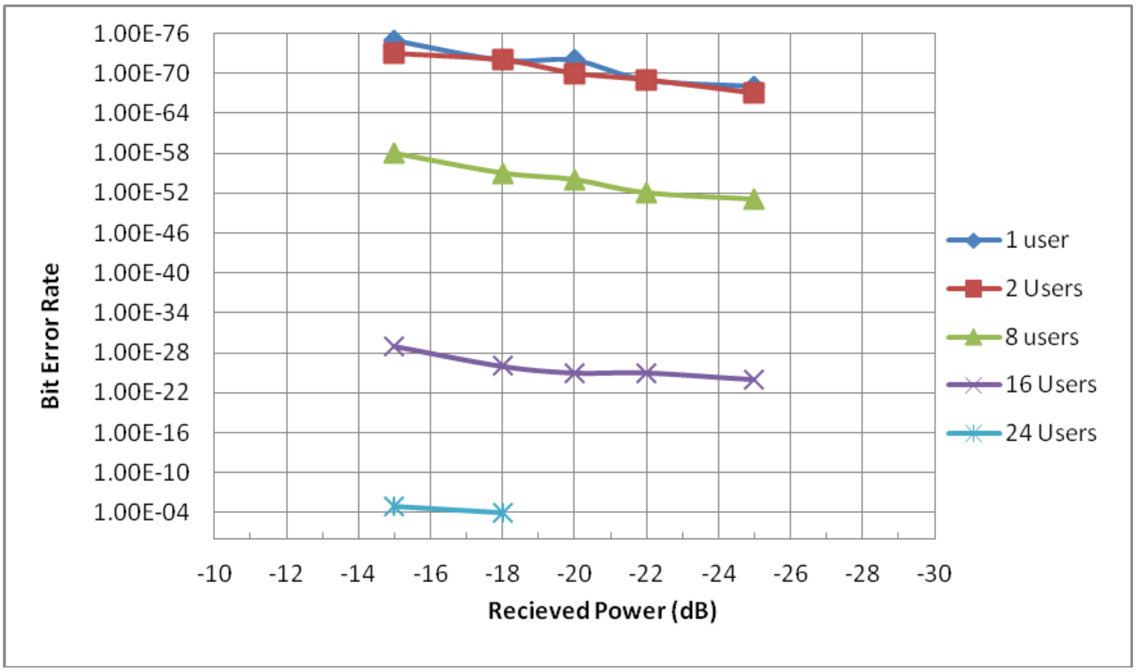


Figure 5.14 Bit Error Rate Versus Received Power at different no of Simultaneous users for 1Gbps W/T code based OCDMA System

Results show that the system performance is better when received power is higher. As the received power is decreases from-15 db to -25 db the bit error rate also decreases from 1.00e-58 to 1.00e50 for 8 users. Similarly the no of users increases 1 to 25 the bit error rate performance degrades as represented as 5.10, 5.11. The 1 Gbps OCDMA systems can accommodate 25 users very elegantly with -15 db received power for bit error rate of e-9. But if the received power is limited to -25 db this system accommodates 10 users only. So it is recommended to use this system at -20 db received power up to -16 no. of simultaneous users with very good BER of e-12.

CHAPTER 6

CONCLUSION

The Optical CDMA system has been designed using these W/T matrix code and WDM type components. A computer simulation using optsim simulation software was used to access the propagation of these codes at high data rates, over a long span fiber. The optical CDMA system has been designed for 1Gbps data rate with different values of received power. A comparative BER and Eye Diagram analysis of high speed OCDMA system for asynchronous concurrent communication of multiple users has been done. The architecture has been proposed for a no. of users with different values of received power and different value of BER has been calculated.

Results shows that the present system can accommodate 24 users for permissible bit error rate of 10^{-9}, with -15 dB received power at 1Gbps rate respectively. If received power is kept low i.e. -22 dB, The W/T code based OCDMA system can support 14 users with extremely low BER for 1Gbps bit error rate. The current OCDMA system is designed for Metropolitan Area Network (MAN) that is 60 km applications which can further be extended for long haul transmission by using optical amplifier to overcome transmission losses and other similar improvements in the system design.

References

1. J.A.Salehi: Code Division Multiple Access Techniques in optical fiber networks- part 1: Fundamentals principles. *IEEE transaction on communications*, Vol.37, No.8, Aug 1989, pp 824-833.

2. Weiner, A.M. Heritage, J.Prakash and Salehi.: Encoding and decoding of femtosecond pulse. *Optics Letters*, Vol.13, No.4, May 1988,pp 300-302.

3. Prucnal, R.P, Santoro, M.A., Sehgal, S.K.: Ultrafast All-Optical Synchronous Multiple Access Fibre Networks. *IEEE Journal on Selected Area In communications*, Vol.4, No.9, 1986, pp 1484-1494.

4. Prucnal, P.R., Santoro, M.A, T. R: Spread Spectrum Fibre-Optic Local Area Network Using Optical Processing. IEEE/OSA *Journal of Light wave Technology*, Vol.4, No.5, May 1986, pp 547-554.

5. Jawed, A.Salehi and C.A. Brackett: Code Division Multiple Access Techniques in optical fibre networks part-2: System performance analysis, *IEEE transaction on communications*, Vol.37, No.8,Aug 1989, pp 834-842.

6. Jawed. A.Salehi, F.R.K Chung, and V.K Wei: Optical Orthogonal Codes:Design, analysis and application. *IEEE Trans. on information Theory*, Vol.35, No.3, May 1989, pp 595-605.

7. H.Chung and P.Kumar: Optical orthogonal codes- new bounds and an optimal construction. *IEEE Trans. on Information Theory*, Vol.36, No.4, July 1990, pp 866-873.

8. A.S. Holmes and R.R Syms: All optical CDMA using "quasi-prime" codes. IEEE/OSA *journal of Light Wave Technology,* Vol.10, No.2, Feb 1992, pp 279-286.

9. S.V Maric, Z.I. Kostic, and E.I. Titlebaum: A new family of optical code sequence for use in spread-spectrum fiber-optic local area network. *IEEE Trans. on communication*, Vol.41, No.8, Aug. 1993, pp 1217-1221.

10. G.C. Yang and W.C. Kwong: Performance Analysis of Optical CDMA with prime codes. *IEEE electronic Letters,* Vol.31, No.7, Mar. 1995, pp 569-570.

11. W.C. Kwong, P.A Perrier, and P.R. Pruncal: Performance comparison of asynchronous and synchronous code division multiple-access technique for fibre-optic local area network. *IEEE trans.on communication*, Vol.39, No11, Nov 1991, pp 1625-1634.

12. S.V.Maric: New family of algebraically designed optical orthogonal codes for use in CDMA fibre-optic networks. *IEEE Electronic Letters,* Vol.29, No.6, Feb 1993, pp 538-539.

13. A.J. Mendez, R.M. Gagliardi, V.J. Hernandez, C.V. Bennett, and W. J. Lennon, "Design and Performance Analysis of Wavelength/Time (W/T) Matrix Codes For Optical CDMA," *IEEE Journal of Light wave Technology*, Vol. 21, pp: 2524-2533, November 2003.

14. A.Stok and E.H. Sargent. "Lighting the Local Area: Optical Code-Division Multiple- Access and Quality of Service Provisioning". *IEEE Network*, Vol. 14, pp: 42–46, November/December 2000.

15. Bin Ni and James S. Lehnert, "Performance of an Incoherent Temporal-Spreading OCDMA System with Broadband Light Sources" *Journal of Light wave Technology,* Vol. 23, No. 7, July 2005.

16. K. Yu, J. Shin, and N. Park, “Wavelength-time Spreading Optical CDMA Systems Using Wavelength Multiplexers and Mirrored Fibre Delay Line,” IEEE Photonics. Technology Letters, Vol. 12, No. 9, pp. 1278–1280, September. 2000.

17. M.S. Anuar, S.A. Aljunid, N.M. Saad, A. Mohammed, and E.I. Babekir, “Development of a Zero Cross-Correlation Code for Spectral-Amplitude Coding Optical Code Division Multiple Access (OCDMA).” *UCSNS International Journal of Computer Science and Network Security*, Vol.6 No.12, December 2006.

18. S.A. Aljunid, M. Ismail, A.R. Ramli, B.M. Ali and M.K. Abdullah. “A New Family of Optical Code Sequence for Spectral Amplitude Coding Optical CDMA Systems.” *IEEE Photonics Technology Letters*, Vol. 16, No.10, October 2004.

19. F. R. K Chung, J. A. Salehi, V. K. Wei, “Optical Orthogonal Codes: Design, Analysis, and Applications,” *IEEE Transactions on Information Theory*, Vol. 35, No. 3, May 1989.

20. I.B. Djardjevic and B. Vasic “Novel Combinatorial Constructions of Optical Orthogonal Codes for Incoherent Optical CDMA Systems” *Journal of Light wave Technology*, Vol. 21, 2003.

21. S. Yegnanarayanan, A. S. Bhushan, and B. Jalali, “Fast Wavelength-Hopping Time Spreading Encoding/Decoding for Optical CDMA.” *IEEE Photonics Technology Letters*, Vol. 12, No. 5, May 2000.

22. L. Tanceski, I. Andonovic, “Wavelength hopping/time spreading code division multiple access systems,” *Electronic Letters*, Vol. 30, No. 9, pp: 721–723, 1994.

23. J. Mendez, J. L. Lambert, J.-M. Morookian, and R. M. Gagliardi, “Synthesis and Demonstration of high speed, bandwidth efficient optical code division multiple Access (CDMA) tested at 1 Gb/s throughput,” *IEEE Photonics Technology Letters*, Vol. 6, pp: 1146–1148, September 1994.

24. Vincent J. Hernandez, Antonio J. Mendez, Corey V. Bennett, Robert M. Gagliardi and William J. Lennon. “Bit-Error-Rate Analysis of a 16-User Gigabit Ethernet Optical-CDMA (O-CDMA) Technology Demonstrator Using Wavelength/Time Codes.” *IEEE Photonics Technology Letters*, Vol. 17, No. 12, December 2005.

25. Thomas H. Shake, “Security Performance of Optical CDMA against Eavesdropping”. *Journal of Light wave Technology*, Vol. 23, NO. 2, February 2005.

26. D.E. Leaird, Z. Jiang and A.M. Weiner, “Experimental Investigation of Security Issues in OCDMA: A Code-Switching Scheme” *IEEE Electronics Letters*, Vol. 41, No. 14, 2005.

27. Hwan Seok Chung, Sun Hyok Chang, Bong Kyu Kim and Kwangjoon Kim, “Experimental Demonstration of Security-Improved OCDMA Scheme Based on Incoherent Broadband Light Source and Bipolar Coding.” *Optical Fibre Technology,*Vol.14, pp: 130–133, 2008.

28. E. Inaty, H. M. H. Shalaby, P. Fortier, and L. A. Rusch, “Multirate Optical Fast Frequency Hopping CDMA System Using Power Control,” *Journal of Light wave Technology*, Vol. 20, No. 2, pp. 166–177, February. 2002.

29. Paul R. Prucnal Optical code division multiple access: Fundamentals and applications.’*CRC press*,2006

30. Nasaruddin and Tetsuo Tsujioka, “Design of Reconfigurable Multiweight Wavelength-Time Optical Codes for Secure Multimedia Optical CDMA Networks.” *IEEE Communications Society ICC*, 2008.

31. F. Khans fid, H. Taylor, and R. Gagliardi, “Design of (0,1) Sequence Sets for Pulsed Coded Systems,” *IEEE International Symposium*, 1990.

32. Dr. T. Srinivas, Archana k, Vijay. P. Sompur,Simulation and Performance analysis of OCDMA System base on 2-D W/T Codes, “*Annual IEEE 2011*.