Performance Analysis of Optical Wireless Communication Systems for Security Enhancement

A Thesis

Submitted in partial fulfilment of the requirements for the award of the degree

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in

Electronics and Communication Engineering

Submitted by

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Certificate

I, Rupinder Kaur hereby certify that the work presented in this thesis entitled " **Performance analysis of optical wireless communication systems for security enhancement**" in fulfilment of requirement for the award of the degree of the Doctor of Philosophy in Electronics and Communication engineering Department, Thapar Institute of Engineering Technology, Patiala, is an authentic record of my own work carried out under the supervision of **Dr. R.S. Kaler**, Sr. Professor, Electronics and Communication Engineering Department, Thapar Institute of Engineering Technology, Patiala, India.

The matter presented in this thesis has not been submitted in any other university or institute for the award of any degree or diploma.

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(Rupinder Kaur)

Date: 20/12/2022

Signature of Candidate

This is certified that the above statements made by the candidate is correct to best of my knowledge.

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ABSTRACT

The internet requirement is ever increasing demand and to combat this demand of different internet services such as high-quality multimedia, smart cell phones, online gaming and shopping, cloud computing etc. The optical communication is the heart of networking system which supports high capacity and data rate. In order to meet the exponential growth in internet services and to cope up with the present users, there is immense need of high-capacity wireless networks. There are certain limitations that exist in both short distance and long haul when condition of large capacity needs to be fulfilled. In the past, multiplexing with electrical techniques was used to meet the capacity requirement, but in that case the data rate achieved was lower. Although with incorporation of WDM technique the capacity increased and rate escalated little.

Optical code division multiple access (OCDMA) technique has become the prominent technology to support high capacity and multiple transmission of data with complete coding and synchronization. This coded feature of OCDMA technology provides high security level in comparison to the existing techniques. The studies revealed that in case of simple transmission of data with OCDMA technique leads to traffic jam and eavesdropping. Hence, security leakage has become a major concern in these networks. The data is easily interpreted by the eavesdropper and either jammed or modified. Thus, the main motive of this thesis is to increase the security level in IS-OWC networks by making availability of linearly polarised modes and multiplexing methods to avoid eavesdropping.

Initially, the issue of cross correlation in IS-OWC networks is addressed. For eliminating cross correlation in IS-OWC system, different existing one-dimensional codes (MD code, Double diagonal weight, random diagonal code and EDW code) are discussed. Further, an enhanced code than the existing ones is presented that also improved bandwidth efficiency. In most of the suggested codes, cross correlation is present either due to variable weight or fixed code length. Therefore, code comprising of features like minimum multiple access interference and bit error rate with zero cross correlation is evaluated firstly. A novel code called zero cross correlation resultant weight is proposed to eliminate cross correlation in the IS-OWC networks. It is depicted that the data is transmitted without compromising the performance of the system.

Further, to increase the capacity of OWC system mode division multiplexing is taken into consideration. The effect of mode division multiplexing with various types of spatial modes ($LG_{11\text{-}15}$/$HG_{11\text{-}15}$) for improving the capacity of the system is analysed. Also, the security

leakage issue due to lack of dual polarization has been discussed mathematically. It can be determined that overlapping among the users caused cross correlation that eventually degraded the system performance. Hence, it is observed that to achieve minimum MAI and BER, users are sent at different modes. The absence of modes can easily result in low performance of the system as capacity will lower and even the data rate will be impacted. Hence, to novel mode division multiplexed strategy is opted to increase the data rate of correct information. An IS-OWC network is simulated with desired frequency range and it is revealed that the data can be transmitted securely without any sort of eavesdropping.

The less development in the security area poses many challenges as there is either overlapping or breaching of the data during transmission over a single mode. The existing MDM systems require improved MUX and DEMUX which support multiple modes, fibres which support spatial modes, optical amplifiers capable of operating with minimum components on multiple modes. The optical wireless communication is dominating the field of communication and also in the sensing region. The OWC is capable to perform even for long distances and in case of non-line of sight region. The positive features of OWC comprise of low weight, compact size, immune to EMI, low power requirement and low price. These days security is of major concern in all areas, hence to attain enhanced level different type of techniques comprising of efficient codes, modulation schemes and combination of spatial modes are essential. As per the analysis, if modes are combined in the simple coding, then the security is increases to a next level because eavesdropper needs a greater number of combinations to decode the information. Even if more users are employed, it also increases security as probability of detecting correct codeword decreases. A new expression for P (E) has been derived in which a new parameter ‘r’ has been presented which denotes the number of Hermite Gaussian and Laguerre-Gaussian modes. Further it is noted that presence of multiple users at eavesdropper decreases the chance of P (E). In addition to it, in codes like ZCCRW the greater code length leads to more combinations at the eavesdropper thus leading to higher security level.

Finally, the multilevel dual polarisation-based modulation in OWC system is taken into consideration. These days the normal encrypted messages are easily decoded by the eavesdroppers. Hence, to achieve a high level of security, a next level comprising of different polarised modes is employed in the system. An IS-OWC network is simulated with proposed mode selectors and it is analysed that data can be easily transmitted without being lost or misused. The probability of correct data detection by the spy at the receiver is minimized.

Introducing the distinctive features with simple set up and reduced error rate, the proposed ZCCRW code design is capable to cope up with the interference during the transmission by utilizing minimum bandwidth. This investigation can be further enhanced by using mode division multiplexing to increase the system security and speed during transmission of the information. Hence, the work shown in this thesis relates the concept of zero cross correlation in IS-OWC to lower the demand of bandwidth and variable weight as different modes are combined during transmission to avoid eavesdropping. The analytical study of polarization inscribed in modulation techniques has been used for better system performance like high quality factor and eye diagrams. The research provides wide scope in inter satellite communication, military areas and research areas where security is of major concern.

The study includes the establishment of new design, simulation and optimization of a newly developed Is-OWC code named as zero cross correlation resultant weight (ZCCRW) code. Most of the research content has been published in different SCI/SCIE journals as listed below.

List of Publications

The thesis includes following list of SCI publications:

1. R. Kaur & R.S. Kaler, "Performance of zero cross correlation resultant weight spectral amplitude codes in lower Earth orbit-based optical wireless channel system", International Journal of Communication Systems, Vol. 33, No. 12, 2020

   https://doi.org/10.1002/dac.4456 (I.F:2.156)

2. R. Kaur & R.S. Kaler, "Performance and security analysis of novel ZCCRW codes in lower earth orbit-based MDM-OWC incorporating hybrid modulations", Journal of Electrical Engineering, Vol. 72, No. 1, pp. 46-52, 2021.

   DOI:10.2478/jee-2021-0007 (I.F: 0.885)

3. R. Kaur & R.S. Kaler, "Performance Analysis of multilevel dual polarization OCDMA based modulation using different codes in MDM-OWC system", OAM-RC, vol. 17, pp. 1-2, 2022. (I.F: 0.441)

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Rupinder Kaur

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List of Acronyms

OWC	:	Optical Wireless Communication
RF	:	Radio Frequency
IS-OWC	:	Inter- satellite Optical Wireless Communication
WDMA	:	Wavelength Division Multiplexing Access
TDMA	:	Time Division Multiplexing Access
CDMA	:	Code Division Multiplexing Access
LP	:	Linearly Polarized
MDM	:	Mode Division Multiplexing
ZCC	:	Zero cross correlation
MD	:	Modified Diagonal
DDW	:	Double Diagonal Weight
ED	:	Enhanced Diagonal
RD	:	Random Diagonal
ZCCRW	:	Zero cross correlation resultant weight
SAC-OCDMA	:	Spectral Amplitude Coding Optical Code Division Multiple Access
MZM	:	Mach-Zehnder Modulator
1D	:	One Dimensional
2D	:	Two Dimensional
FEC	:	Forward Error Correction
MAI	:	Multiple Access Interference
BER	:	Bit Error Rate
QF	:	Quality Factor
RMS	:	Root Mean Square
LG	:	Laguerre Gaussian
HG	:	Hermite Gaussian
DQPSK	:	Differential Quadrature Phase Shift Keying
MDRZ	:	Modified Duobinary Return to Zero
DRZ	:	Duobinary Return to Zero
CSRZ	:	Carrier Suppressed Return to Zero
FBG	:	Fiber Bragg Grating
LEO	:	Lower Earth Orbit
EM	:	Electromagnetic Modes

SNR	:	Signal to Noise Ratio
ER	:	Extinction Ratio
CW	:	Continuous Wave

CHAPTER 1
INTRODUCTION

1.1 Wireless Communication

Wireless communication is the communication in which there is use of EM waves to send out data among different users. In other words, “Wireless communication is the technology which employs optical carriers to send information from one end to another end through any unguided channel that may be either gratuitous region or atmosphere. The wireless technology is considered to be the upcoming frontier for high-speed connections due to its features like easy deployment, compact size, large bandwidth availability, unauthorized spectrum available, minimum strength intake and high security level. Wireless communications can be broadly divided into two categories, namely outdoor and indoor communication.

For communication in the construction area, the indoor communication either employs visible light or IR because employing a physical connection is practically tough purpose. For outdoor communication that is also known as free space communication there are further subcategories also, named as terrestrial and space optical links. These types comprise of satellite to ground, ground to satellite or building to construction area links. The key component of modern society is wireless communication to the currently ever-present cellular communication. Wireless transportation has changed the means society’s task. Wireless communication has numerous benefits in excess of the previous booming wired message. The advantages of wireless communication are its portability, suppleness and range. Portability means the independence offers to user to use a hand-held device like a cell phone. Suppleness means we can insert or eliminate devices into live networks with no change in hard ware part. Cellular radio technology allows users to move over a huge area providing them a large range. The present-day demand is to fulfill the high speed and high-level security criteria while sending the information [1].

Optical wireless innovation for the communications among two satellites within the area has numerous blessings over radio frequency transmissions. WOC can provide fast records transmission in the scope of Gbps and it's far worked within the infra-red locale of the electromagnetic frequency range. From past a few years of the transmission of signals for Optical Wireless Communication (OWC) conversation, laser supply is sent which might be inescapable piece of optical wireless communications. The traditional wireless connections had been depending on the range of radio frequency. Optical communication has high-quality over conventional microwave and radio verbal exchange and consequently eliminated the usage of these communications in most of the applications. Due to peer pressure at the RF in satellite TV for PC communication, optical verbal exchange primarily based satellites are more and more deployed in space to provide bits of very superior quality. Until now, the transmission changed into normal with the end goal that there has been no switch communication among satellites. Now not with status, optical laser conversation empowers us to get to the hand-off transmission that diminishes time and cost of the networks. Switch transmission is the hand off with one satellite then onto the next without the immediate hyperlink. Fig 1.1 depicts the diagram of wireless communication system [2].

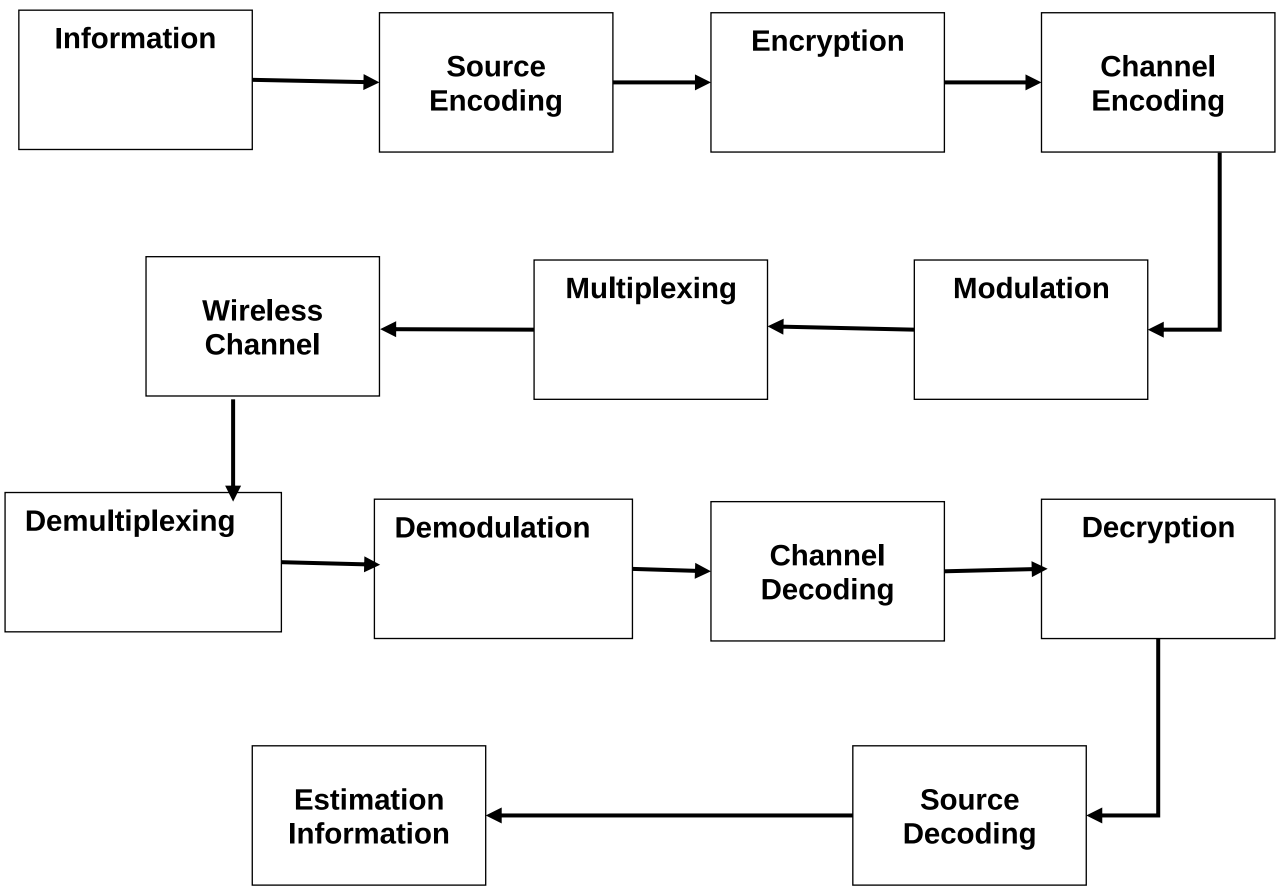
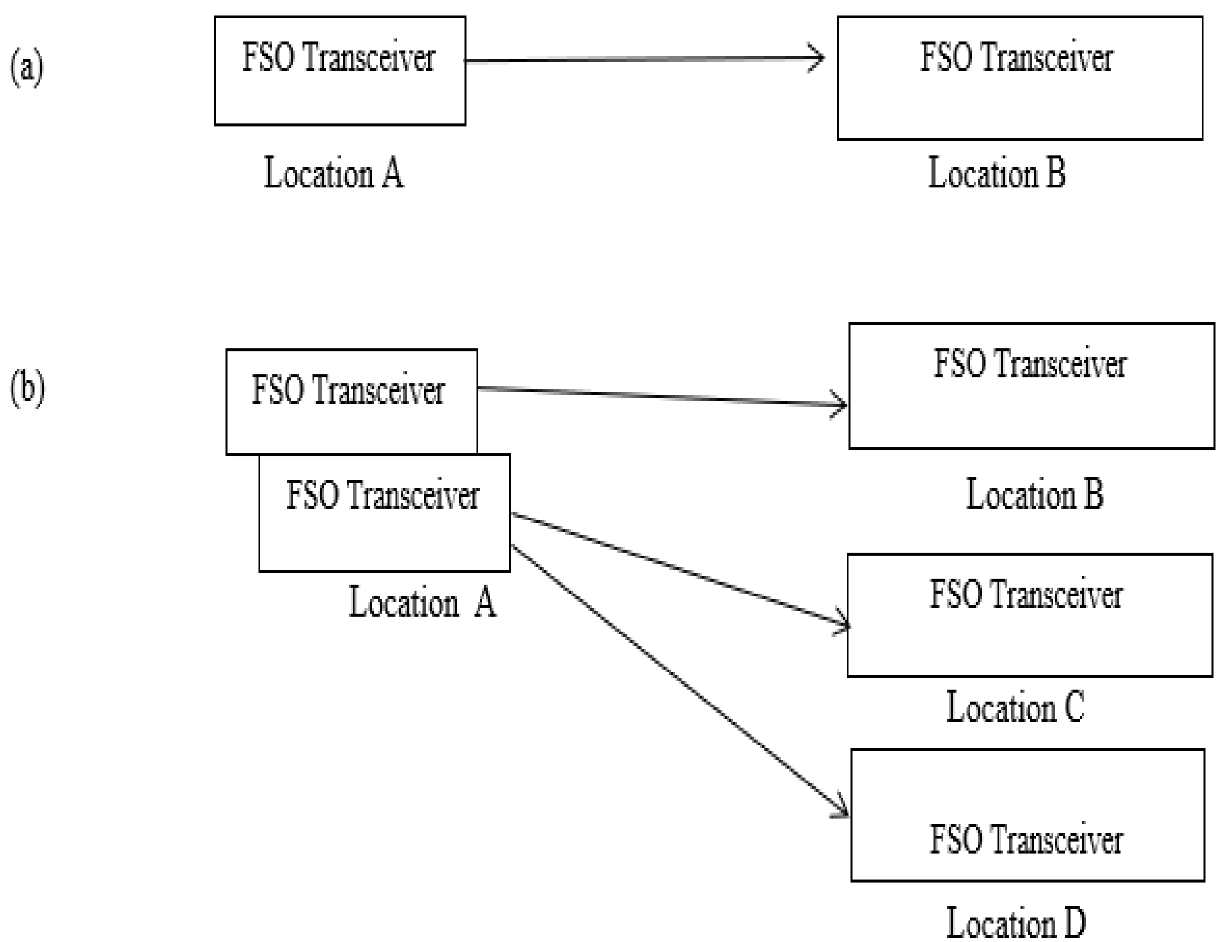


Fig 1.1 Block Diagram depicting main components of wireless communication system.

1.2 Link Configurations

There are two major factors on which the selection of optical connectors is based namely (i) detector's view which is whether view is narrow or broad and (ii) transmitter's beam angle which includes level of direction. As per the type of optical connectors there are mainly four types of link configurations possible namely, direct line of sight (LOS), undirected LOS, multi beamed quad distributed and diffused link. In direct line of sight link, the size of the angle of the transmitter as pole and the FOV receiver is comparatively very small [3]. The working of the transmitter and receiver is interlinked with each other. This interdependence is beneficial for establishing point-to-point link of internal communication. Few pros and cons of LOS link communication are given below:

1. High energy efficiency as losses are comparatively less
2. Reduce multipath distortion
3. Improved budget



(c)

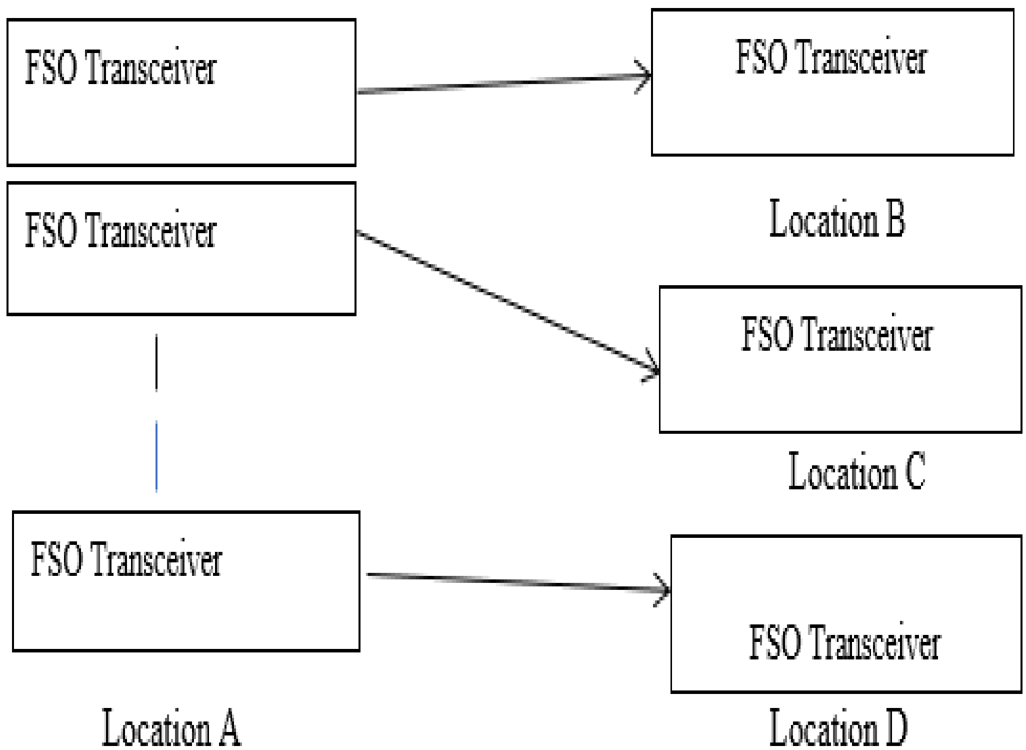


Fig 1.2(a) Point to point Link (b) Multipoint Link (c) Point to multipoint Link

Links are most affected by blocking (or secretion); hence, they fail to provide mobility in particular internal environment. Although it is ideal for certain applications [4]. This gives the symbolic depiction of the linkage. The technique has been used from a long time with low data rate employed in electronic devices that use remote control systems such as audio or visual equipment like television. This technology provides feature of point-to-point connection among the portable electronic components like in laptops [5]. Fig 1.2 shows diagram of (a) Point-to-point Link (b) Multipoint Link (c) Point to multipoint Link

1.3 Fundamentals of Optical Wireless Communication

Wireless communication system has three fundamental blocks: Transmitter, Receiver and Channel. Fig. 1.3 shows the block set up of wireless communication.

Likewise, in the context of wireless communication, the sender consists of an electronic path and by means of the help of transmitter or antenna, it produces EM waves which are sent throughout liberty

[6]. This EM energy transmits from one side to another side via free space etc. During the period of transmission, different noises occur keen on the pointer [7]. The recipient receives this indication. If the receiver wants to effectively guess the message, then the receiver has to be familiar on terms by means of the natural world of distortions arise with the path. The procedure is to analyze the method how channel act to EM waves is referred to as Channel Estimation [8].

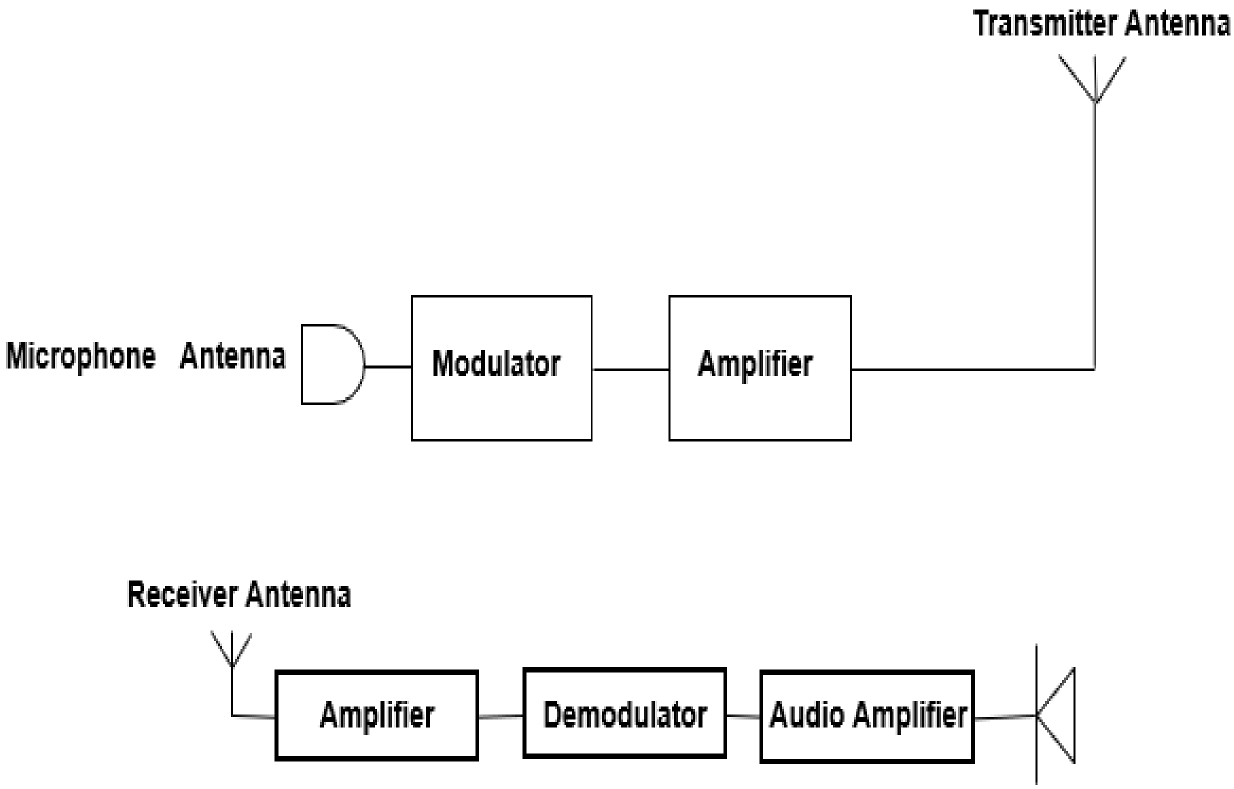


Fig. 1.3 Wireless communication system

1.3.1 Transmitter

The main function of transmitter is to send the input signal in suitable form over the channel through which communication takes place. The transmission over the channel is known as modulation. During the communication, if verbal exchange is required in the channel, its main function is to offer a pathway among the output part of transmitter and input part of the receiver [8-9].

There are different strategies present to transmit a shrewd message through an optical channel. These two strategies are analog or virtual also called digital. Both of these strategies have superiorities and downsides for each strategy. In case of digital approach, its edge encompasses the subsequent:

1. High noise immune system in the channel in addition to it, outdoor interference immunity that is not

feasible to avoid us in the verbal exchange communication.

2. Provides flexible machine operations owing to the availability of high-tech digital devices.
3. The transmitter can achieve specific type of signals such as video statistics, voice statistics and pc recordings in proper equal format. The message signals can be encoded to attain high security level for confidential records [10].

1.3.2 Communication Channel

This optical communication is a type of optical verbal exchange, in which the records transmission channel is installed via space which is free. The transmission takes place in an unfastened area (for instance air) which acts as a medium, the transmitter part is fulfilled by a low-power light amplification by stimulated emission of radiation (laser). It is because of the channels in optical fiber exchange (OFC) and FSO exchange are extraordinary, as noise factor is one of the instances. The exceptional of optical signal transmission through Wi-Fi relies upon the atmospheric characteristics such as wind, fog, sunlight, rain, blizzard, turbulence and mild from various resources [11]. The different noises present in the receiver, for example thermal noise and shot noise are also depicted with direct detection and on-off keying technique whose impact is analyzed at the output electrically. For calculation of bit error rate with respect to distance is also achieved by considering the above-mentioned noises and different type of losses present at the receiver end and in the channel. In the end, the simulation of complete FSO based system is by means of combination of both the noise factor present at the output side and losses occurring over the channel [12].

1.3.3 Receiver

In Optical communication, receiver is considered to be the most important part because receiver regulates the overall performance of the system on regular basis. The basic function of receiver is to determine the strength of received signal obtained from the transmitter side and extract the desired content from it that may be either digital or analog [13]. It needs to achieve these characteristic necessities such as preferred degree of signal-to-noise ratio. The two unique elements that out way the optical receiver from other type of receivers such as microwave and coaxial cable are the low-noise preamplifier and the photo detector. Collectively they decide the overall cost of the receiver part. Basically, photo detector is a device in which energy is trapped and then converted into electricity with the flow of electrons within it [14].

Fig 1.4 represents the diagram of optical receiver. Recipient sensitivity is defined as low power when a given system requires given access quality rating. It is the basic parameter of the entire laser communication system because it determines everything other than design options. For any given medium - power signal and photons arriving at the receiver, it is distributed evenly over time.

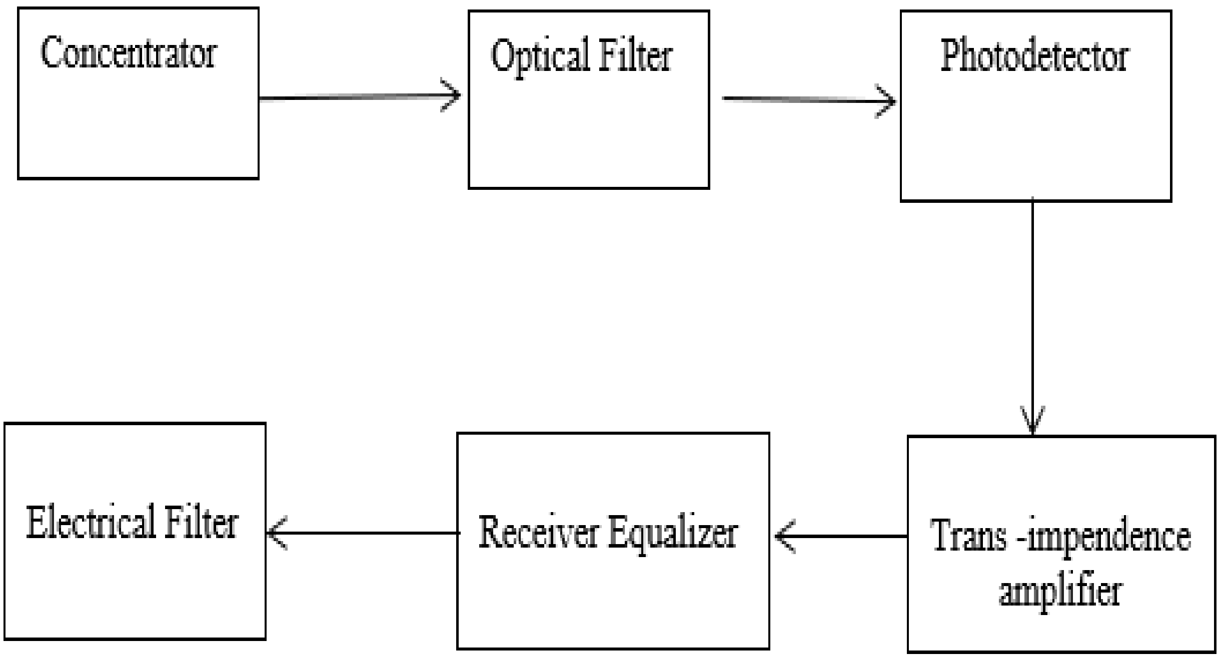


Fig 1.4 Optical receiver

1.4 Optical Wireless Communication

As per the past study related to gain knowledge of various components such as lasers, modulators to analyze performance, European Space Agency tested it in 1977 [1]. The technology related to optical wireless is defined as the communication of laser based light signals. The light signal employed for transmission comprises of frequency of IR type. The medium taken into account for lower layers is air and for region above environmental conditions is taken to be vacuum [2-4].

The main components required for OWC are the recipient and the sender. Transmitter incorporating the light intensity signal, data source and the pulse shaping device. Receiver is section to decode or detect the data with photo detectors. The most common medium chosen for communication over the channel is either vacuum or air for inter satellite communication [5]. As per the research, in EM frequency spectrum, OWC working in the IR region supports speed ranging upto several Gbps.

FSO communication is quite competent and premier technique to cater demand of speedy inter-satellite networks due to high speed, wide band width, antenna of compact size, low weight, high power efficiency and high level of signal security [6].

Optical Wireless transmission is having 3 particular and essential units, for instance, sender, medium (air or vacuum) and recipient. Transmitter additionally incorporates of double facts streams and pulse molding drivers taken after by means of an energy modulator which alternate the electric signal to optical with the nonstop supply of optical pulse from laser.

Requirements for rate of data for satellite communications for viewing, military services, and broadcast apply peer pressure to OWC. The transfer of confidential data safely without security breaching and improving the efficiency of a real user is the main necessity nowadays [6].

1.4.1 Advantages of OWC

- Optical wireless communication systems are much more immune to interference. These systems provide huge data rates up to Gbps. These systems have been investigated from more than thirty years to support high data rates as an alternative to RF Spectrum systems. Optical wireless communication supports unlimited bandwidth range and in the communication systems, the amount of data is directly proportional to bandwidth [15].
- Optical wireless communication systems support high capacity and it contains small wavelength in comparison with the microwaves.
- Optical wireless communication links consists of lasers or LEDS where lasers act as input signal and photo detectors act as output signal. These devices are much cheaper and operate at less cost than RF links [16].
- These systems ensure high security-based technique because the optical signals do not penetrate through the walls like the EM waves do. These are used to provide high security against eavesdropping.
- OWC systems consume very little power as there is minimum path loss. Photodiode present at the receiver end contains very large area and it provides efficient spatial diversity.
- OWC spectrum is unregulated and it is license free, it contains fast deployment, less start up as well as operational cost [17].

1.4.2 Disadvantages of OWC

- Optical wireless systems need the receiver and the detector (photo- sensitive) which consumes very large area for the collection of maximum output signal, which ultimately increase the capacitance of photo detector, thus reducing the bandwidth of receiver.
- There is extra time anticipated to supply a satellite and moreover satellite architectures and development are exorbitant.
- Satellite needs a valid overseeing on everyday durations: in this manner it has to be kept inside the orbit.
- Satellite is available which is regarded as 12-15 years. Because of this truth, one greater dispatch has to be outlined before it moves towards becoming un-operational.
- Various hardware components are consolidated in the system plan. This will increase extra charge of the machine for putting satellites in orbits.
- Account of lower earth and medium earth circles, large quantities of satellites are attractive to conceal great region on the planet. Moreover, satellite transmitter for pc deceivability from earth is for extremely little length which needs brief satellite transmitter for pc to satellite transmitter for pc handover. This leads to intricacy in the system [17-18].

It is well known that free space optics is the best solution to meet the requirement of providing high bandwidth, huge security and unregulated spectrum, but OWC is the technology which overcame the drawbacks of RF and FSO technology [19-20].

Fig. 1.5 represents the diagram of optical wireless communication system. The old technology wireless links were dependent on the frequency range of radio region. Nowadays, this microwave or radio frequency communication is substituted by the all-optical communication owing to several merits as compared to the radio frequency transmission [7]. With the development of the inter-satellite networks, a new strategy is required to meet the ever-increasing demands of high data rate in satellite communication [21].

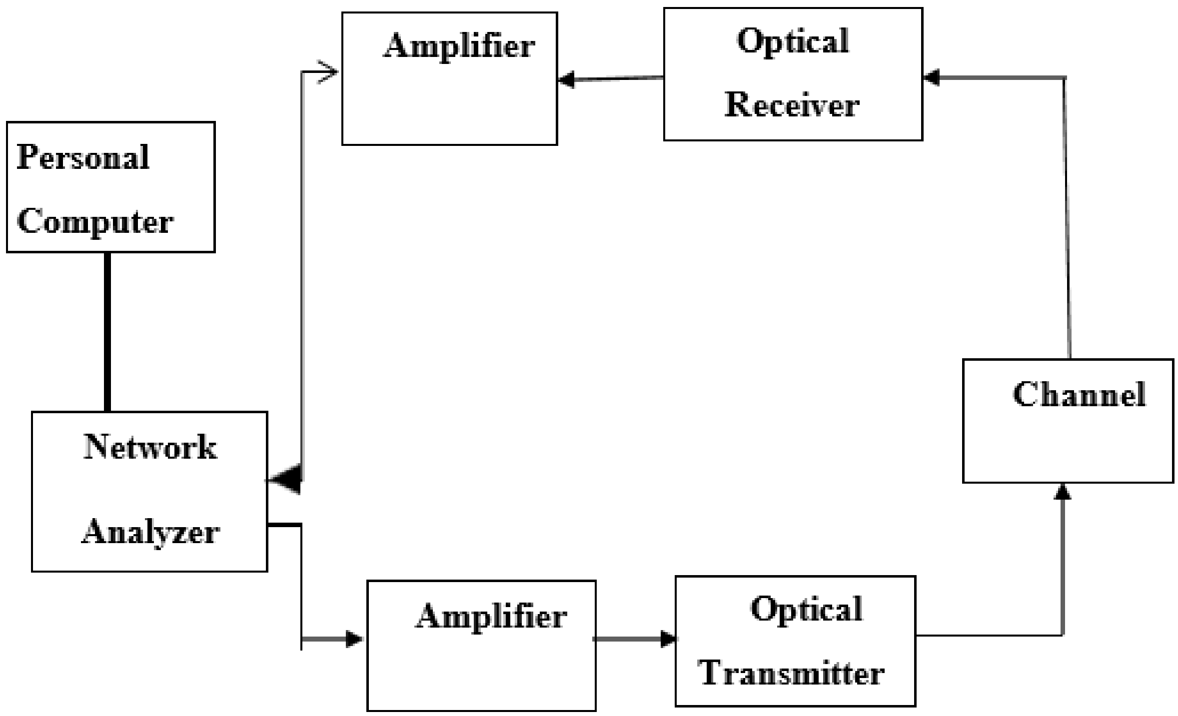


Fig. 1.5 Optical wireless communications

Relay transmission is the hand off of signal from one satellite to another without the direct link with ground station [22]. Data accessing, optical computers and laser beams are the main parts of the OWC [23-24]. There is strong relevance in the FSO and optical wireless technology; the main difference is of the propagation channel. In FSO, the medium is completely air and in satellite major communication takes place in vacuum medium. It is noteworthy that attenuation due to vacuum in inter satellite communications is negligible [25].

A network analyzer is a device that measures the network parameters of an electrical network. Today, network analysts often measure s - parameters because the thinking and transmission of power networks is easy to measure at high frequencies, but there are other network parameter settings such as y parameters and h-parameters. [26-28]

An amplifier is an electronic device that can shoot out signal strength. It is an electronic circuit with two ports that use electric power for attaining more height of the signal used in its input terminals, producing signal of high quality [29]. The amplifier volume produced by the optical pre amplifier is measured by its average output power, input power, gain or current. Amplifier is a type of circuit which comprises of power gain value more than unity [30].

1.5 Basics of Inter- Satellite Optical Wireless Communication (IS-OWC)

1.5.1 Introduction to IS-OWC

With high number of users, the demand for more bandwidth and high data rate is observed. Optical wireless communications systems have developed from fibers having large length to efficient wireless machine. This has eventually caused requirement of optical wireless conversation gadget in area communications. It is so because the range of satellites orbiting around the earth increases twelve months by way of year, a community among the satellites offers a strategy for them to talk with every different person. It is essential for satellites to transmit facts to each another and additionally to relay the records from a satellite transmitter for pc to any other satellite and finally to the ground station. Advanced multimedia feature for customers at every slot and everywhere is the necessity for subsequent generation cell satellite verbal exchange. To meet this demand, it is best to form a community among the satellites with different ground stations. In such cases, to fulfill the demands, OWC is the only way because it provides us with the fastest communication than RF and microwave technology [31-33].

By looking at its advantages, this technology is also employed in space communication. If this technique is employing more than two satellites then it is referred to as inter-satellite optical wireless communication (IS-OWC). If the size of the payload is reduced, then the price and the weight of the entire satellite is also minimized. IS-OWC results in high Q factor, high bit rare, more security and high speed, narrow bandwidth due to small wavelength, further accurate tracking system for LOS and alignment.

Satellite communications are already at par with the satellite communication which employs radio frequency. Although effective performance is the most important aspect, and the main feature is low interference, high level protection of optical wavelengths, for example 1064nm or 1550 nm and lower power requirement. These benefits help with many business ideas, like large connections among satellites and quantum key distribution systems. As the communication technology is depicted to be a technological solution, the path is open to widespread use. This technology is capable of establishing Inter-satellite links, for example LEO to GEO and LEO to LEO, even satellite to global communications [34-35]. The research carried out to make more visible communication channels has enhanced the confidence level for the satellite communication that it can be employed for more type of business categories [36].

These days some attractive business and recreational activities provide communication among people, for instance the transmission of personal information, or transfer of encrypted data. The natural protection of visible links, due to the split beam splitting provides confidence in such business applications. To allow for the widespread use of visible satellite communications, for example, to provide large LEO stars with light terminals, work is yet to be done for achieving efficient laser terminals for communication. In addition to it, there is a high tendency towards small and medium satellites for different observational and scientific activities.

Satellite communications systems, as mentioned in the introduction, typically contain many LEO satellites, as well as global terminals. The most effective option in satellite technology is satellite links, owing to absence of atmospheric influences, like atmospheric disturbances and clouds. Inter-satellite links account for most of the data transfer system. In addition to it, a sub-channel communication should be established, where visual communication can assist RF communication technology [37].

Fig 1.6 shows the diagram of basic function of transponder. A communication satellite transponder is defined as a series of interconnected units which result in formation of a communication channel between transmitting and receiving pens [39]. It is wise application in the field of satellite communication to transmit the acquired signals

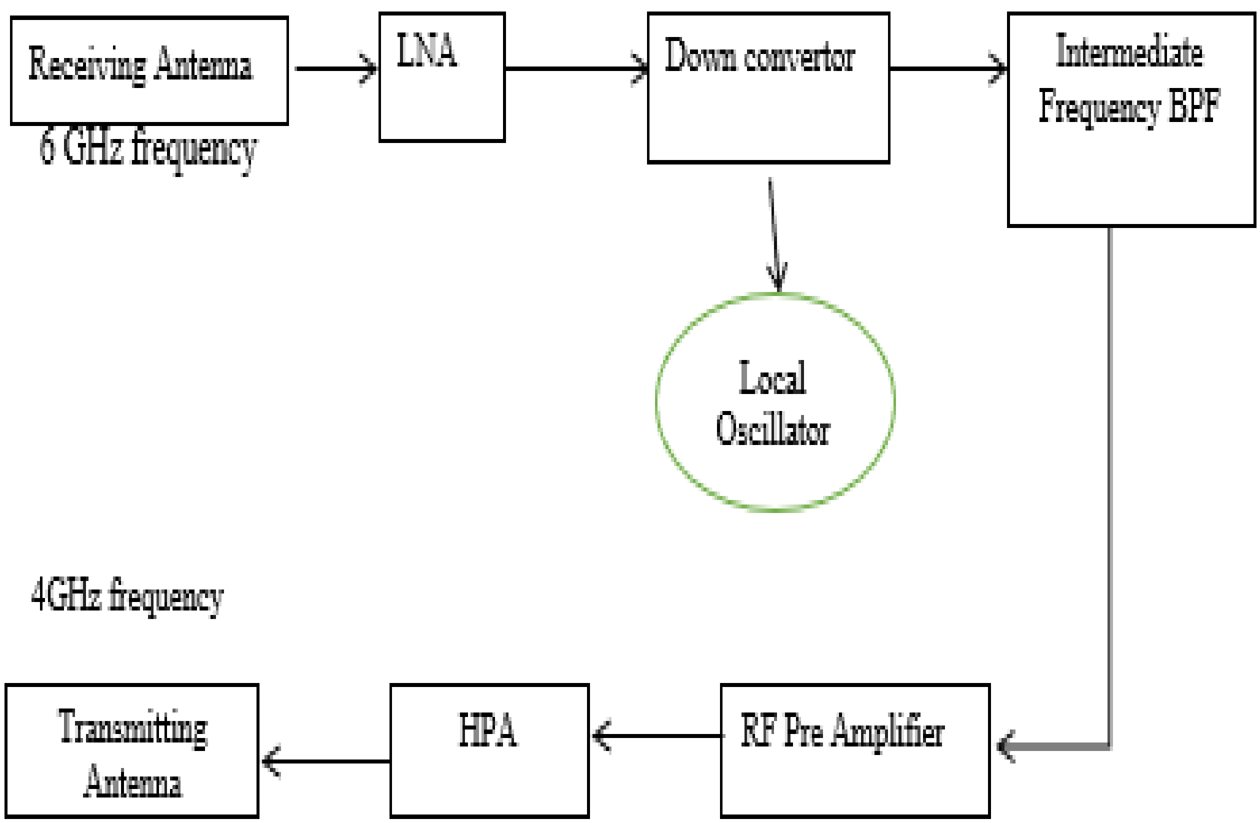


Fig 1.6 Diagram showing the basic function of transponder

The transponder usually comprises of: band-limit input device that may be band-pass filter input, frequency converter (commonly a frequency mixer and an oscillator) used to change the received signal frequency into the desired frequency of the sent signal, low- noise amplifier (LNA) designed to amplify signals received from Earth station (usually very weak, owing to presence of long distance) and band-pass filter power amplifier (it can be either a solid-state or wave-wave amplifier) [40-41].

Satellite communication has emerged out to be the promising technology for global communication links in comparison with terrestrial communication links. Many modulation techniques like WDM, DWDM and coding techniques are used in satellite links using modes has been implemented [42-43]. Military intelligence, weather forecasting and broadband internet services are some of the prominent areas where communication takes place through satellites. Nowadays, coding techniques like OCDMA, Spectral amplitude coding has emerged out as best techniques to achieve huge data rates. OCDMA technique is introduced as it delivers ample number of benefits like non-synchronous access, large bandwidth efficiency and ability to add new channels [44-46]. Fig. 1.7 shows the diagram of Inter satellite optical communications.

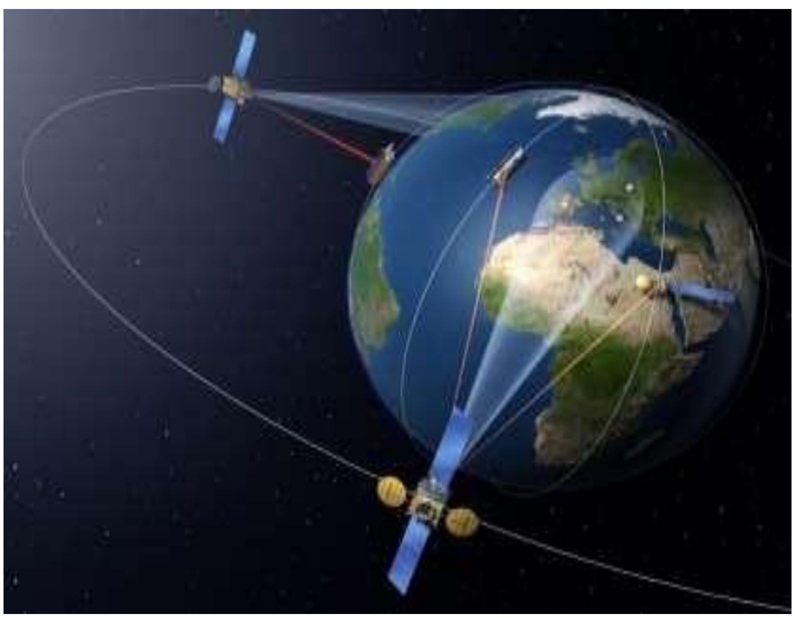


Fig. 1.7 Inter satellite optical communications [45]

1.5.2 History of Satellite Communication

The basic testing part of inter-satellite wireless optical transmission is done by the continuity of events and the integrated components are also focused, for example, lasers, modulators to understand the continuity of these communications [47]. For the first time in 1977, satellite experiments were conducted by the Space Agency of Europe and experimental properties were tested [48]. The European space office and its new work unit were assembled to improve the components used as part of wireless communication and during the 1980s; the European Space office used a semiconductor laser to OWC display also called SILEX [49].

To provide global data on inter-satellite transmission, two satellites called SPOT-4 and ARTEMIS were deployed in space in 2001 for their data transfer to be transmitted and embrace it within the scope of the optical spectrum. With this experiment, another world window was opened and Japan attempted a two-way satellite transmission after this test between two satellites, for example, the Japanese satellite and ARTEMIS. With the Japanese investigation, Germany also conducted a test between SAR-X and a close field infrared test satellite based on new optical. With the continued success of OWC communications, Japan has also shown interest in satellite communications and successfully resolved communications between OICETS and LCT (Light using transmission). The case could cover a connection length of 610 km and continue in 2005, with work being improved on ARTEMIS [50]. Speed of 2 Mbps to 50 Mbps was achieved between OICETS and SPOT-4 [51].

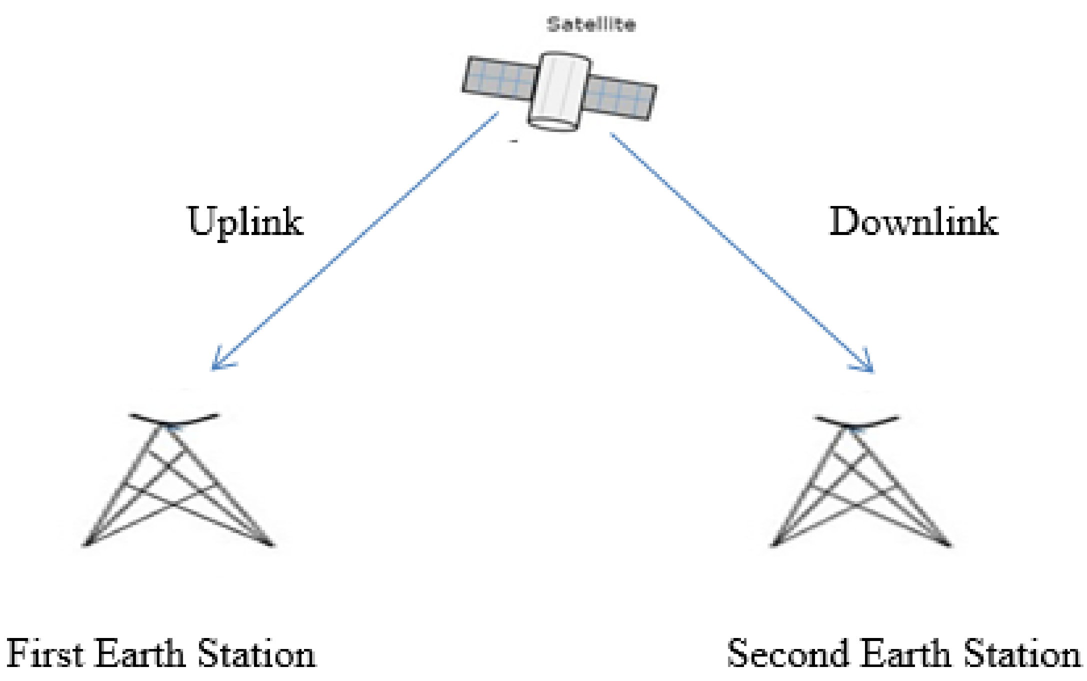


Fig 1.8 Overview of communication via satellite.

1.5.3 Working Principle of IS-OWC

Inter-satellite wireless communication setup along with essential components is depicted in Fig. 1.8 having sender and recipient in different satellites.

OWC is the transmission of signal via air from sender to beneficiary. This faraway communication utilizes a laser as a light supply to bring statistics or sign. Laser goes approximately as a bearer inside the innovation [52]. As call suggests, OWC makes use of wireless medium. OWC is likewise named as laser communication. As the quantity of clients is increasing, the hobby for higher switch velocity and speedy is moreover increasing. For this case, to fulfill those requests, OWC is the primary manner since it offers us the speediest verbal exchange than RF and microwave innovation. With the aid of taking its factors, this innovation is additionally applied for area communication and when this innovation is utilized for the communication among two greater satellites, at that factor its miles called as inter-satellite transmitter for communication which is optically transferred (IS-OWC) [53-54].

For the inter-satellite conversation, facts from the telemetry and following frameworks are calibrated with light signal of laser diode with the consolidation of outdoor energy modulator, proceeding of the signal within the space [55].

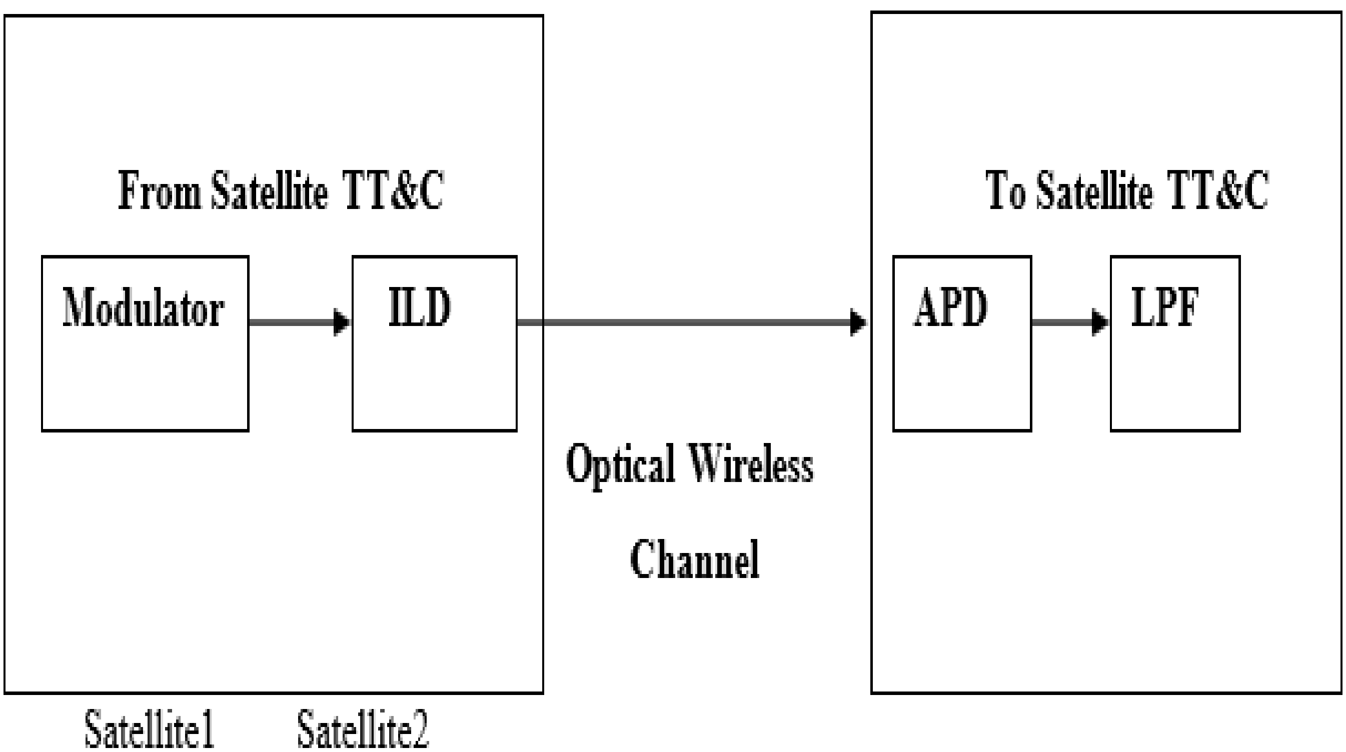


Fig. 1.9 IS-OWC basic architecture for simplex communication.

The main function is that the information is received by the transmitter from satellite's Telemetry block, Tracking portion and Communication system.

Fig. 1.9 IS-OWC depicts the basic architecture for simplex. A single-color light is generated by the laser and it has same phase among serial pulses, therefore used widely due to high radiance. Whenever the transferring of information takes place either by space or air, many problems can occur like Reflection distortion, Diffraction distortion, and scattered distortion [56].

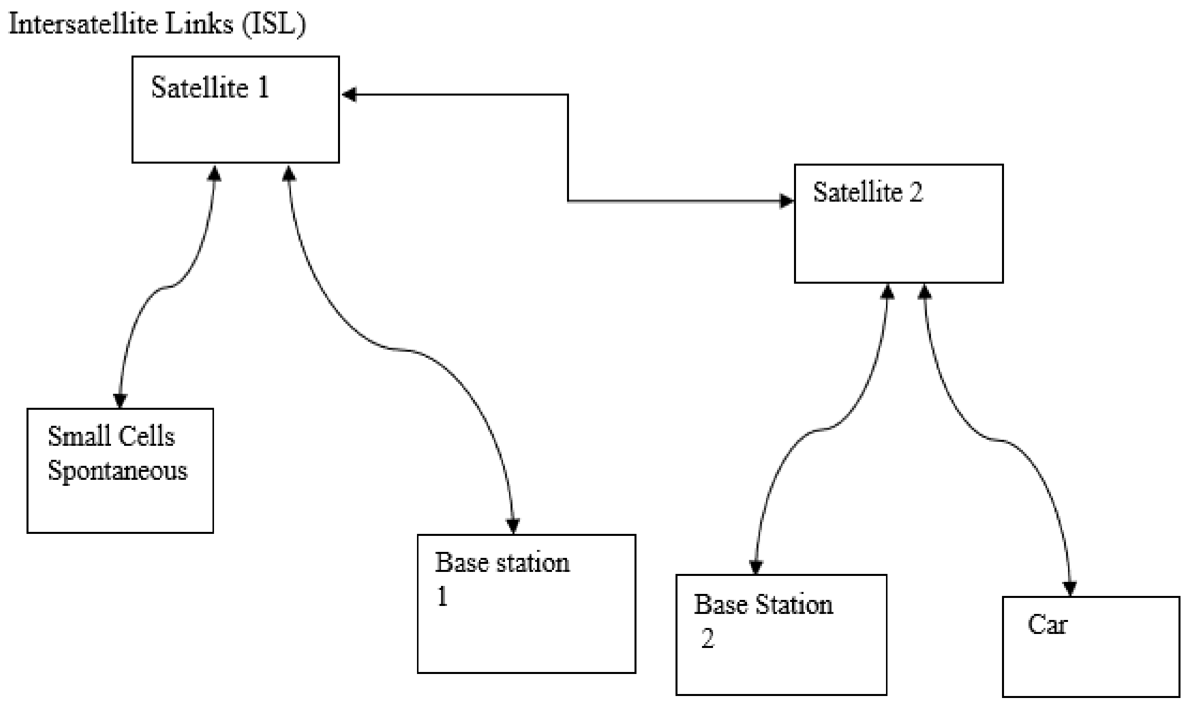


Fig 1.10 Links of Inter-satellite communication

Fig 1.10 shows the diagram representing links of Inter-satellite communication. Currently, after signal transmission through medium, signal is expected to be disconnected. This should happen where the signal is detected using the image detector detected by a low-noise filter. There are mainly two photon counters, for example, PIN and Avalanche photo diode. As shown by the performance hypothesis, they are different. There are various effects of warm sounds shot in these photon counters APD override PIN [57].

The pass filter filters out the sound and is followed by the regenerator to reset the time the signal received in reference to the transmitted information. In this way, making optical remote frame, suitable locations, filters and regenerator are required for better communication. The avalanche photodiode (APD) is also seen in simple structures for long-distance transmission [58]. The APD has its increased sensitivity with the aim of finally strengthening the three-point signal to achieve an improved yield.

Antennas are placed to come across or send the mild. Also, it is vital to observe that due to non-presence of air in optical wireless conversation, beam no longer diverge [59].

For the Inter-satellite communication, data from the telemetry and tracking systems is modulated with intensity light signal of laser diode with the incorporation of external intensity modulator, prior to releasing the signal in the space. Electrical signal or pulses are generated through the different line coders such as non-return to zero owing to the cost efficient and simple pulse generation [60]. Drive of pulses given to modulator that can act as amplitude, frequency or phase modulator. Fig. 1.11 depicts the optical modulation process [61].

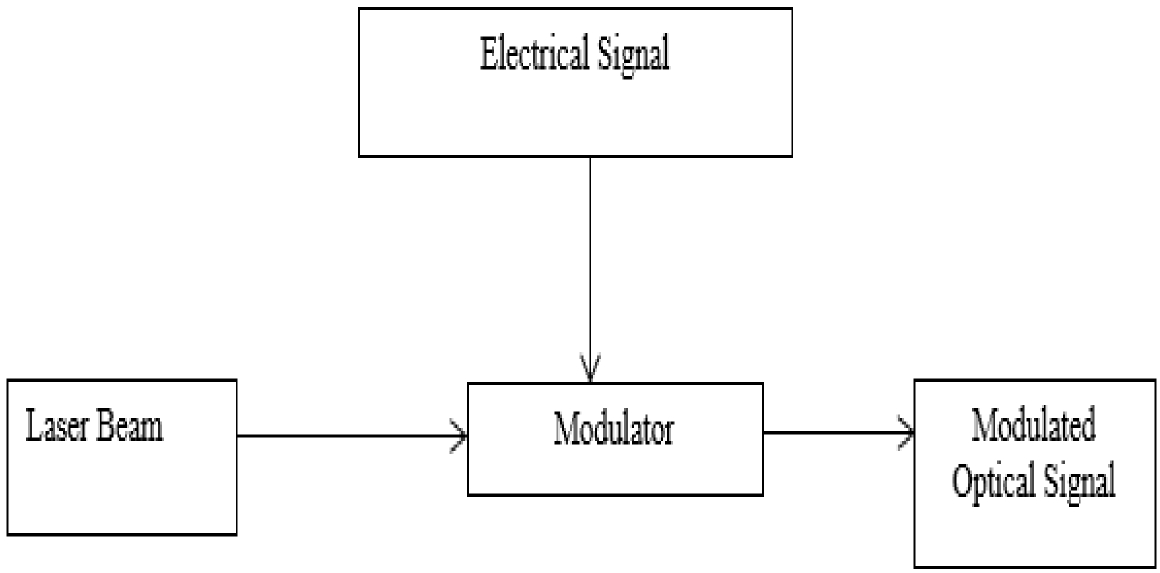


Fig. 1.11 Optical modulation process

An optical modulator is defined as a component employed for modulating light's beam. The beam may either be sent through an optical fiber (i.e., optical waveguide) or propagated through space. On the basis of the parameters present in the light beam that is being operated, modulators are defined as segment modulator, amplitude modulator or polarization modulator. The most effective method to achieve high modulation gain is by modulating the present day's supply, for instance laser diode supply. Such types of modulations fall under the category of direct modulation category, instead of external modulation which is performed by using light modulators. It is because of this only; the light modulators are known as external modulators in fiber optical communication.

There is no attenuation in vacuum and major cause of the attenuation is the distance. In case of free space, different air or weather instabilities effects the data and this case is not true for the IS- OWC due to non-presence of the atmosphere [62].

The optical modulation either allows to encrypt the data on the optical service wave or control the entire optical wave. The opposite method which recovers the encrypted data is known as demodulation. There are different types of optical modulation present, that may be labeled in numerous exceptional ways.

1. By keeping the particular optical field parameter that is modulated, the optical modulation can be categorized into different modulation techniques such as frequency modulation, amplitude modulation, angle modulation, diffraction modulation or spatial modulation.

2. Optical modulation can be either defined as external or direct modulation. The external modulation is achieved with an optical wave which employs a distinct optical modulator for changing either one or more features of the wave. The direct modulation usually comprises of an optical source, that is either a laser or a LED. There is no need of a different optical modulator in direct modulation.

3. The optical modulation can be defined on the basis of physical mechanism present at the backend of optical susceptibility. It includes magneto-optic modulation, acousto-optic modulation, all-optical modulation, electro-optic modulation, and many more [63].

4. On the basis of the geometry combinations between the modulated wave and the modulating optical wave, the optical modulation is defined as either longitudinal or transverse modulation. The implementation of signal takes place along the propagating path in case of longitudinal wave. The direction of signal is perpendicular with respect to the propagating path of the wave [64].

5. The optical modulation can also be obtained on guided or unguided optical waves. Similarly, the optical modulator either takes the shape of waveguide tool or bulk tool. The waveguide modulator is employed for modulating a guided wave and the bulk modulator is employed for modulating an unguided optical signal [65].

   Optical lens focuses the beam to the other satellite for line-of-sight link. Antennas are placed to detect or send the light. Also, it is important to note that due to absence of air in optical wireless communication, beam dies but not diverges. It is basically a telescope to send and receive the signal as depicted in Fig. 1.12 [66].

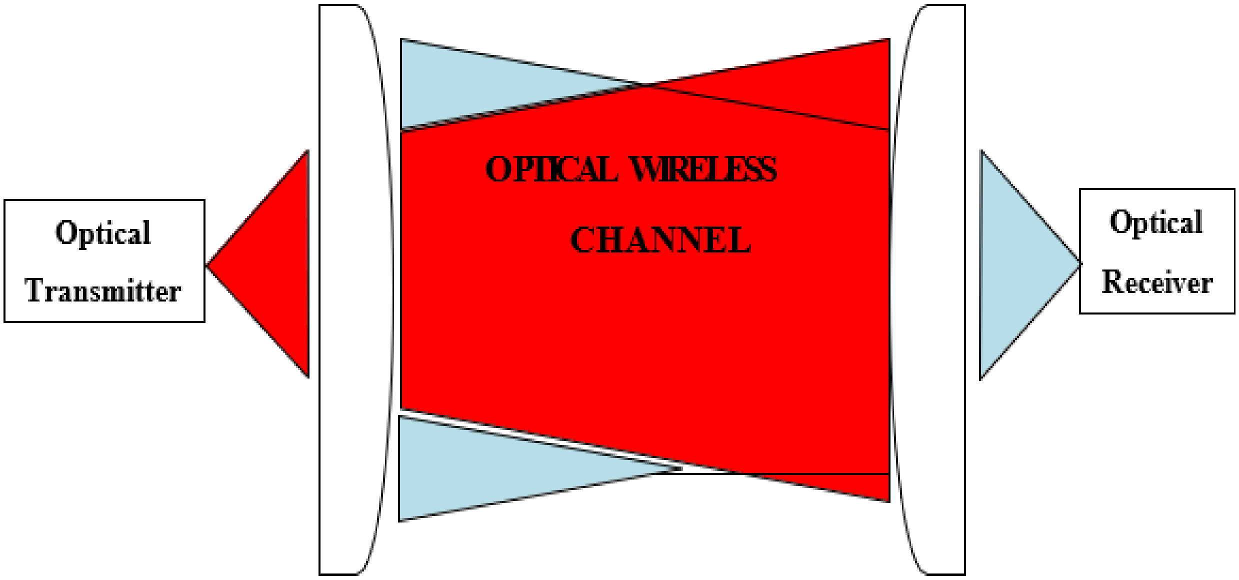


Fig. 1.12 Optical antennas at transmitter and receiver side

The decoding is through the detection of signal via photo detector followed by the noise remover via low pass filter. There are mainly two detectors such as PIN and Avalanche diode which have different effect of thermal and shot noise. Low pass filter removes the noise followed by the regenerator to re-time the received signal with reference of transmitted data [67].

Avalanche photodiode (APD) has its own gain as it amplifies received signal up to 3 folds [67]. This phenomenon occurs when charged electrons exposed to high field of current as well as strikes the atoms to accumulate other carriers [68-71].

1.6 Polarization Techniques

Variations of polarization have a large number of applications in optical wireless communication by exploiting additional radio the background of the resources for the separation of time, frequency, space, etc. [72]. In addition to it, the flexibility of the rules of segregation it has unique and important features that are not sensitive to it power dissipation power and phase noise caused by the local oscillator, instead it has promising promotion in the use of electrical power and channel capacity [73]. Therefore, modeling of separation and division is used classification of network signal as contained parameters. The details draw more attention. The study of polarization fluctuations begins from optical wireless communication. The difficult analysis of binary separation shift keying modulation were introduced in [74], in which two orthogonal splits are immediately changed to represent different fragments. Variation of polarization uses a radio service with more freedom, though still facing others application challenges for wireless communication.

1.7 Optical Orbits for Satellite Communication

Orbit is defined as the path followed by the object either across a star or across any elliptical shape and further the satellite is placed in the foci of an ellipse. Fig. 1.13 depicts the orbits of satellite around the earth in optical wireless channels.

The orbit is defined as the curved direction that an object takes in space (including an asteroid, planet, spacecraft or moon) around any particle or item because of the presence of gravity. The gravity convicts' objects in area that have mass which is to be interested in different close by gadgets. When the attraction is more and it brings them close with enough momentum, they can occasionally start to orbit across each other [75].

It is observed that items of approximately similar mass either orbit with each other or with different objects present in the center. In our solar system, the earth is orbited by the moon, and solar is orbited by the earth, but it does not mean that the larger element remains stable at its point.

There are number of factors on which the quality of the orbit depends for a particular satellite, like what function the satellite has to perform in the allocated channel.

The partitioning of the orbits required for particular satellite is done on the basis of the distance to be covered with respect to ground. The lower most orbit is defined upto distance of 1000km and is named as Lower Earth Orbit (LEO). The distance range form 5000-25000km is named as Medium Earth Orbit (MEO) that is the second orbit. MEO is considered to be an important orbit as it covers large distance for surveillance. The orbit which covers distance greater than 36000km is termed as geostationary earth orbit (GEO). The time slot of satellites in GEO orbit is 24hours [75-76].

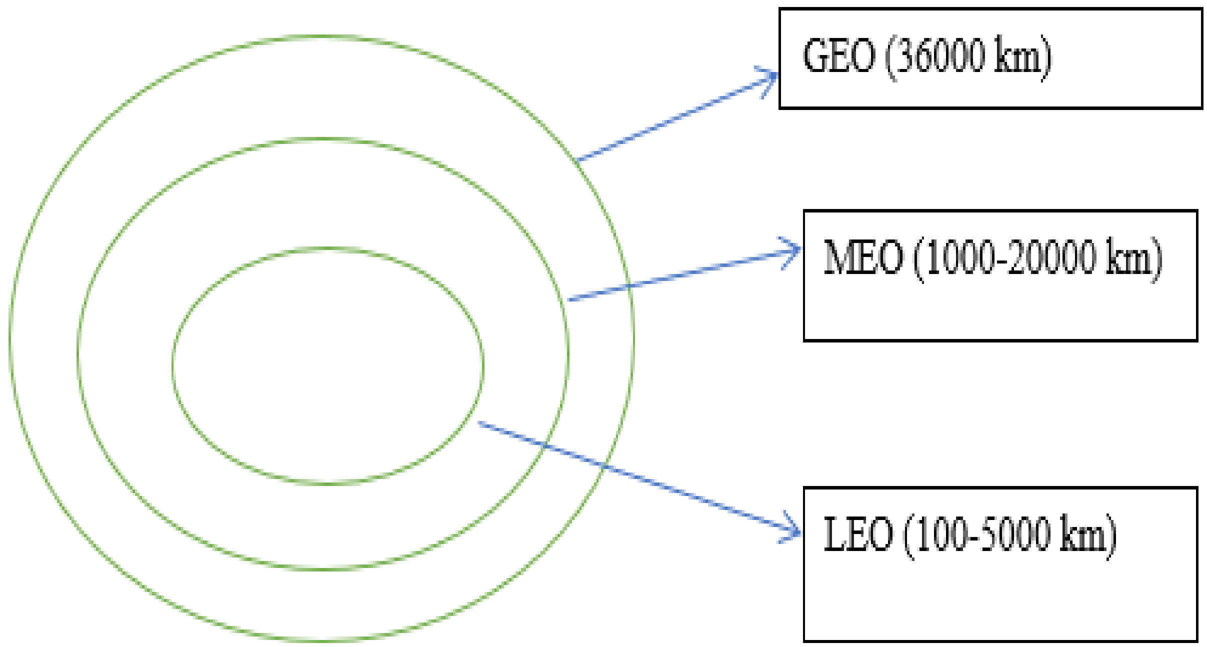


Fig. 1.13 Earth Satellite Communication Orbits

1.7.1 Geostationary Orbit

The direction followed by satellites in GEO is from west towards east as per the rotation of the earth and the total duration taken to complete it is 23hours 56min and 4sec- through journeying at a speed exact as that of the rotation of earth. This is the reason which make satellite appear as stationery in the GEO throughout the complete orbit. On the way to flawlessly match rotation of earth, the speed of geo satellites has to be approximately 3 km/sec at a height of 35,786 km. This distance is a whole lot farther from earth's floor in comparison to most of the satellites. All these needs are fulfilled in optical wireless communication system. Geo is employed by most of the satellites which are functioned to stay at particular location for long duration such as telecommunication related satellites. So as per this requirement, the antenna on this planet may be constant to always remain pointed in the direction of that satellite transmitter for pc without shifting. This satellite can even be employed for forecasting weather; due to the fact they can always take a look at unique regions to look how climate vary there. Satellites in this orbit cover a huge variety of globe in order few as three similarly-spaced satellites are capable to offer close to international coverage. It is so because if a satellite transmitter for pc is at a distance from earth, it is capable to cover large areas right now [75-77].

1.7.2 Low Earth Orbit

The lowermost orbit termed as low earth orbit (LEO) is an orbit which is nearest to surface of earth. It's far usually at a height just even at less than a 1000 km or sometimes even just at a distance of 160km from the earth – that's very close in comparison to the other orbits, but still the distance is large from the surface of earth.

As per the comparison, most of the commercial aero planes fly at just 14km altitude which means the LEO distance is still 10 times more than it. In contrast to the GEO satellites, the LEO satellites do not orbit in a constant orbit across the earth but they have tilted planes. This depicts that the number of possible routes in LEO for satellites are more owing to which this orbit is more widely used for OWC by the researchers.

The distance of LEO is near to the earth due to which it is very beneficial for number of reasons. This is the most preferred orbit for imaging by the satellites because it is convenient to capture photographs easily and with more clarity. This orbit is also for global stationing as it is preferred by the astronauts because the distance to be travelled is less and less complications are present. The speed of the satellite to orbit is approximately 7.8 km in two days and the satellite transmitter takes nearly 90 min to cover the earth, which means the earth is covered nearly 16 times in every afternoon [75,78].

1.7.3 Medium Earth Orbit

The medium earth orbit (MEO) consists of large number of orbits in between the other two orbits namely the LEO and the GEO. Just like LEO, this path is also at a large distance from the earth and it does not require to take specific path across the earth and it is less employed by the satellites comprising of simple programs.

It is very less used by the satellites functioned to work as navigation, for instance Ecu Galileo. Galileo uses navigation all over Europe and it is employed for different kind of navigations, for example detecting jets and even for directions in smartphones. Galileo employs group of satellites to cover huge elements of particular area [79].

1.7.4 Polar Orbit and Sun Synchronous Orbit

The satellites present in polar orbit follow the direction from north to south and not like GEO where the direction is from east to west, almost touching the poles of the earth. The satellites which either pass the north or south pole just with deviation of 20-30levels of decibels is termed as polar orbit. Polar orbits fall in the category of LEO because the distance of polar orbit is just in the range of 200-

1000km [79-80].

One of the particular types of polar orbit is Sun-synchronous orbit (SSO). The satellites which travel in SSO across the polar orbit are usually in synchronization with the solar system. This depicts that they might be in synchronization having fixed and equal function with respect to the sun. Also because of this, every time the satellite visits the same spot at the same time – for instance, crossing the metropolis of Paris on every single day in the noon exactly. Therefore, it is preferable in OWC systems.

It is because of this, the satellite will continuously have a look at a point on earth as if continuously on the equal time of the day, that fulfills the requirement of some of the applications; for instance, the method which scientists and others who employ the satellite transmitters for computer photographs can make a comparison by comparing the adjustments made in the past years.

That is due to the fact, in case you want to display a place by means of taking a series of pix of a sure area throughout many days or months, or maybe years, then it would not be quite helpful to calculate at hours of darkness and then at noon – you need to take every image as further because the preceding photograph as viable. Consequently, scientists use photo collection like these to research how climate patterns emerge, to assist are expecting climate; when tracking emergencies like flood or forest fires; or to build up statistics on long-time period issues like cutting of trees or rising sea levels.

On regular basis the satellites present in the SSO are properly synchronized to make them consistent with each other– this is due to the fact with the aid of regularly riding a sundown or sunrise, they will never have the solar system at a distance where the shadow of earth is present. The satellite transmitter for pc in a SSO would normally be at a height of around 600 - 800 km. When at an altitude of 800 km, it will be routing at a speed of around 7.5 km with accordance to 2d [76, 80].

1.7.5 Transfer Orbit and Geostationary Transfer Orbit

For movement form one to another orbit is called transfer orbits. While releasing the satellites from earth and carrying to area with release motors consisting of Arianne five, the satellites aren't always positioned immediately on their very last orbit. Regularly, the satellite rather positioned on a switch orbit: an orbit in which, with the aid of the usage of pretty little power from integrated vehicles, the spacecraft or satellite has the possibility to pass from either of the orbit to another orbit.

This feature permits the satellite transmitter pc to obtain high altitude path without requiring the vehicle to actually cover the whole distance which requires extra energy. Hence, this is considered to be a short method for changing the orbit. To achieve GEO in such a manner is one of the most common examples of switch orbit and it is referred to as geostationary transfer orbit (GTO).

There are different types of eccentricities present in the orbits either an elliptical or a round shaped. In the round orbit, most of the times the satellite is at an equal distance from the surface of earth– however on a tremendously eccentric orbit, the course looks like that is present in ellipse.

On a relatively eccentric orbit like this, the satellite pc transmitter can speedily range from very distant to very near to floor of earth depending on the orbit in which the satellite is moving. In case of transfer orbits, the engines are used by payload for movement from one orbit having eccentricity equal to one to another orbit, that helps it to move in the right direction to higher or decrease orbits.

On the goal vacation spot, the payload is released by the rocket that units it off on an elliptical orbit, then blue line is followed that helps to release the payload far away from earth. The largest distance it covers form the earth's surface is known as apogee and the nearest point is referred to as perigee [81]. Thus, to fulfill the requirement of high security in OWC such type of orbit is chosen.

1.8 Multiple Access Techniques

The physical layer comprising of various techniques to support multiple access and improve the transmission speed in OWC plays an immense role. Multiple access techniques are employed in optical wireless communication channel like TDMA where every single user is assigned a particular time slot, WDMA where every single user is assigned a particular wavelength can be used to increase throughput by simultaneously accessing the fiber [80-82]. A couple of strategies are given to approach method of allowing numerous clients to ship data indicators at the same instant of time over the medium of communication with the useful resource of simultaneously offering the bandwidth to all the customers. Get right of access to techniques are mainly classified into 2 awesome parts which encompass asynchronous and synchronous. In neighborhood region networks, wherein records transmission is variable and numerous collisions occurs are inner optical medium is referred as asynchronous. As the spectrum resources are finite, it is code division multiple access (CDMA) which made it feasible to have a greater number of users enjoy the similar bandwidth slot at same timing.

1.8.1 Time Division Multiple Access (TDMA)

TDMA is employed in second generation mobile applications like Global System Mobile (GSM) Communications, iDEN, Personal Digital Cellular (PDC) and IS-136, along with it the standard Digital Enhanced Cordless Telecommunications (DECT) for cellphones. The technique TDMA was initially introduced to satellite communications programs by Western Union on its Westar 3 telecommunications satellite in 1979. These days it is widely employed in communication related to satellites [81-82], passive optical network (PON) above traffic networks from location to operator and to combat radio systems [83].

TDMA is a one of the forms of time division multiplexing (TDM) partition, having a special feature that it has multiple transmitters and not like other techniques a single transmitter is attached with a single receiver. It is noted that in uplink case to a base station form a cellphone, it is tough owing to movement of cellphone and changing the time ahead of the time needed to make its transfer match its transmission gap.

Certain disadvantages of TDMA are given below: -

1. The major drawback of TDMA technique is that it creates disruptions to frequencies that are directly linked to the length of time. This is a type of buzz which can be heard sometimes when a TDMA cellphone is kept near the speakers or radio.
2. One more drawback of TDMA technique is presence of "dead time" between the time zones which limits the availability of effective bandwidth of the TDMA slot. It is employed due to difficulty in analyzing if the channels send the data in timely manner. The cellphones are required to adjust and check it on regular basis to verify that the transmission is being received timely, owing to more duration in case of signal originated from the base station. It is also meant that the larger TDMA set ups have more drawbacks related to bandwidth constraints [84].
3. In TDMA, the complete statistics transmission is obtainable to the client but just for a limited timeframe. In maximum of the instances, several channels are separated and given specific time frame because of which every channel occupies bandwidths at specific instances. In a particular TDMA framework, every single channel includes a pre-appointed scheduled vacant time, that interleaves with the availabilities of different channels. TDMA calls for cautious time synchronization when you consider that customers share the information transmission within the frequency area.

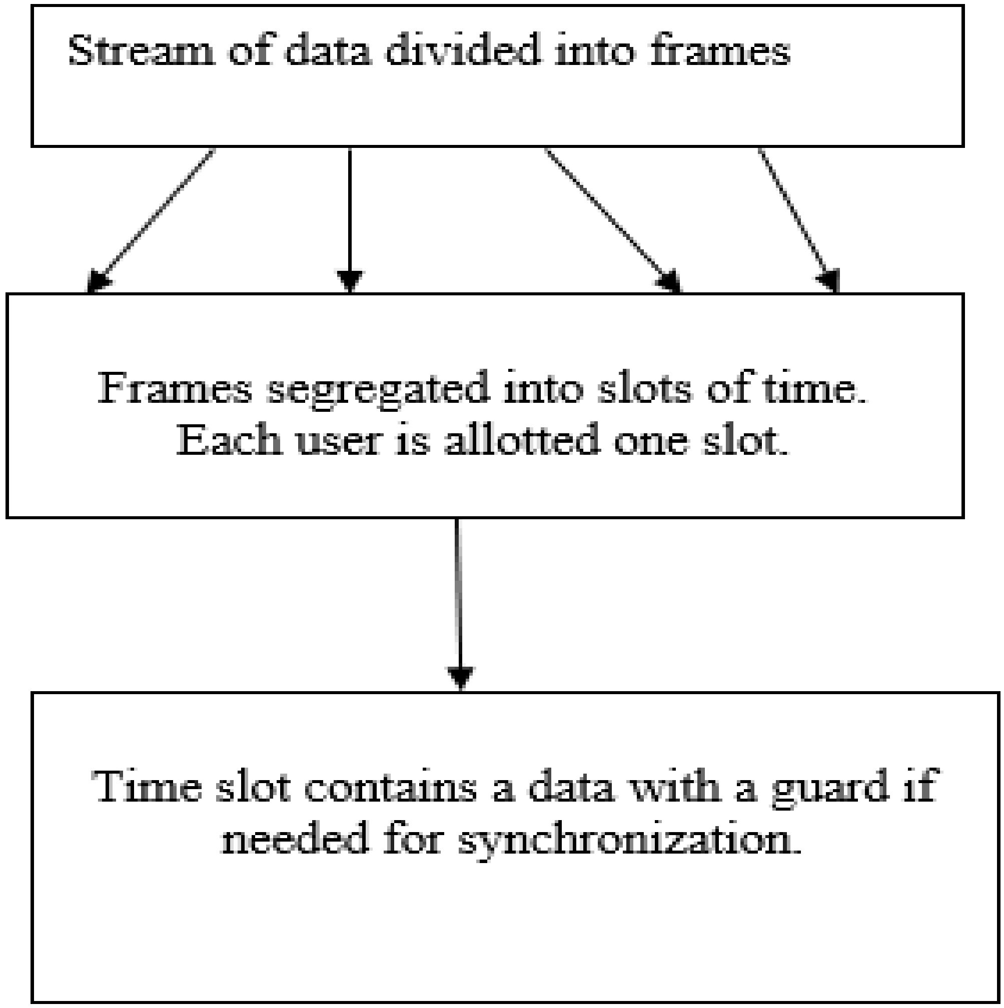


Fig 1.14 Diagram explaining TDMA system of communication

Interference due to multiple channels in TDM is less or almost negligible. Due to higher range of channels, time department gaps between the information channels are critical. TDMA employs distinguish time intervals for verbal exchange and reception. In mobile phone calls, whilst a consumer actions from one give up to every other with one mobile then customer ought to stumble upon a name loss if there is absence of spare time slots [85]. Fig. 1.14 shows the diagram explaining TDMA system of communication.

1.8.2 Wavelength Division Multiple Access (WDMA)

In analog as well as digital transmission, multiplexing of wavelength has an easier entry to this technique. Analog services also broadly practiced the usage of wavelength division. In WDMA framework, information switch capacity is isolated into quantity of channels and every channel includes a separate optical transmission channel round a center wavelength. The channels are appointed simply when requested through the customers. Few indoor optical wireless communication (OWC) systems consisting of WDMA methodology have been reported.

Seeing that every channel is transmitted at an exchange wave length, they can be shortlisted utilizing an optical channel. In this, every single purchaser is relegated a settled space of wavelength during the complete duration thus making it easy to make proper utilization of it. If you want to separate the adjoining channels. These bands aren't used for the statistics modulation, however, best included in the system for wavelength separations. But it also wastes the bandwidth by obtaining the channel of communication [86-87]. To augment the entire capability of system by employing wavelength department we want to percent greater range of wavelengths or channels. Fig. 1.15 represents the diagram showing the concept of WDMA system of communication.

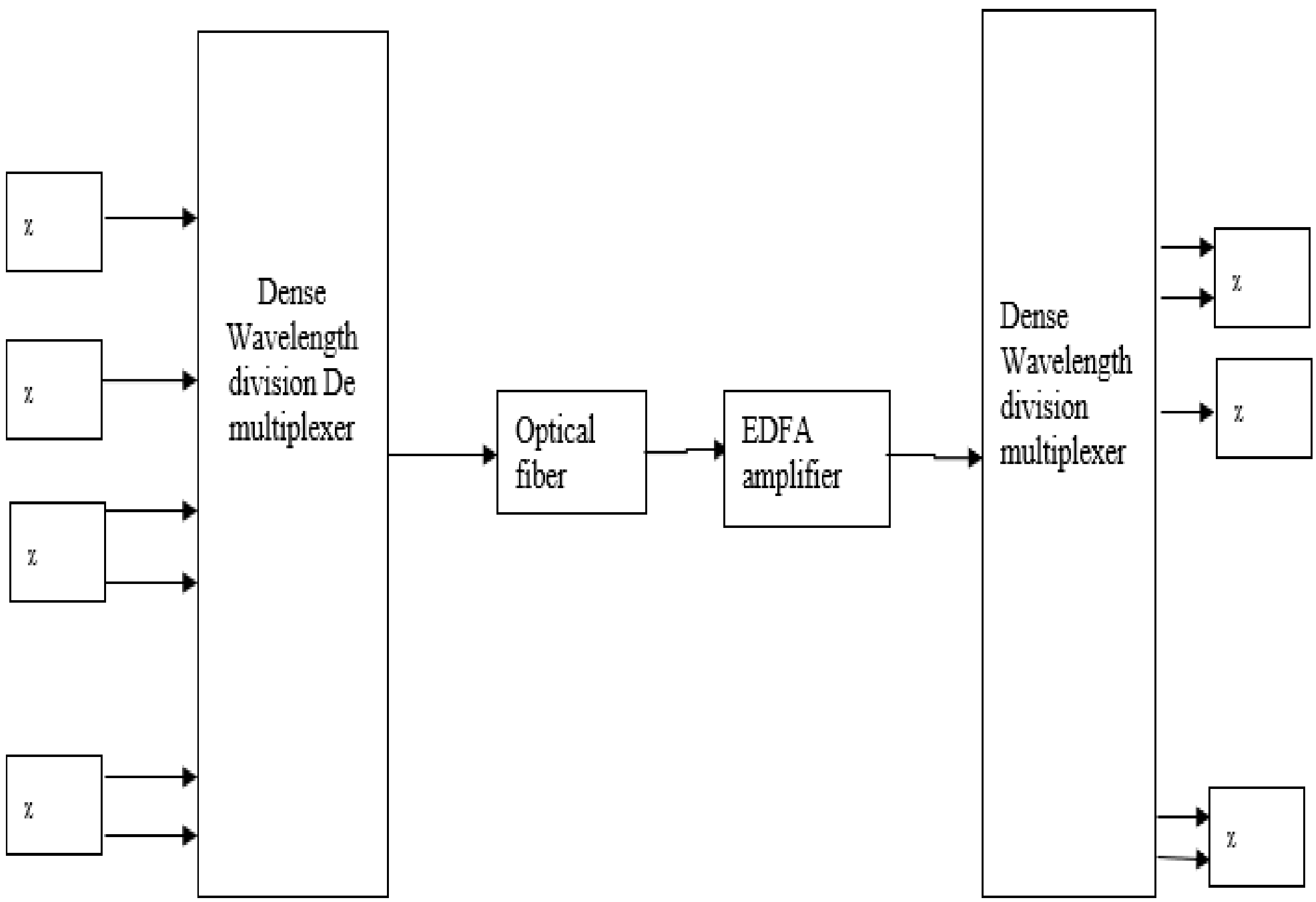


Fig 1.15 Diagram showing the concept of WDMA system of communication

1.8.3 Optical Code Division Multiple Access (OCDMA)

OCDMA provides ability for high spectral efficiency, improved security level, decentralized and simple network control. In OCDMA system, the eavesdropper can detect the signal only if he knows the specific code. To improve security, the code length or number of users can be increased but it leads to MAI that may result in a smaller number of active users [88].

In code division technique, much like the wavelength and time division, as an example in WDM, wave length of a couple of channels and in TDM technique, specific time slots are present for every particular channel. In CDMA technique, various codes are employed to meet the need of multiple users with many channels over an equal exchange medium. In CDMA technique, every single client is allotted the complete range on regular basis. CDMA technique uses one of the spreading codes to spread baseband facts at a faster speed than the transmission. The transmission of flag takes place which is below the noise level. To select the authorized chip of a specific code, a correlate is traced at the receiver facet and along with it blocking of other chips of different users is done with the help of slender clear out. The codes are delivered with the set of ones and zeroes efficiently in contrast to the baseband data. The remuneration is known as bit price at which the code unfold is known as the chip rate. The unfold spectrum allows asynchronous more than one time access to local area networks [89-90].

Therefore, it is the requirement of OCDMA technique to perform switching, multiplexing feature and adding and dropping of signals over different channels or particular network for simultaneous access is important in contrast to existing TDMA and WDMA techniques. The OCDMA technique has a special feature to permit flexibility for more than one user to use multiple channels at same time in the similar time slot and with same frequency slot along with particular unique code in optical region.

The benefits include the ability to support speed, simultaneous communication and tolerance of recurring interruptions. The performance of CDMA in contrast is different because it usually requires directed light waves (e.g., fiber cable), coding is inserted more strongly than the amplitude of light wave, different codes do not connect tightly, and the receiver directly applies the acquisition. This proposes the term 'optical code division multiple access'. The particular type of CDMA codes named as pseudo-orthogonal mostly require large bandwidths to show the embedded data, so that visible CDMA can sometimes be measured as bandwidth. The two categories of OCDMA codec's which work effectively with the bandwidth requirement of WCSs are the optical matrix CDMA and the non-compliant spectral CDMA. In addition to it, wireless communication systems may sometimes require to support variable amount of data (for various services), and these two types of OCDMA are tolerant of data rate changes. It is an appropriate topology for different techniques like LAN consists of a star and, multimedia consists of a tree and data distribution.

1.8.3.1 Advantages of OCDMA

1. OCDMA technology is one of the promising technologies to enforce all-optical networks because of its potential for elevated bandwidth ability, simplified and decentralized network manage, progressed spectral performance and robust statistics protection [91]. The large cardinality and versatility in coding in OCDMA makes it lenient limited which means that the variety of customers may be varied in step with network demand in preference to TDM and WDMA. The new customers may be accommodated on the basis of elevated bit error rate [92].
2. The security sensitive information consisting of navy transactions, monetary transactions, scientific records and so forth, which is transmitted privately, is concluded through the net. The layer which is physical of the net is generally the optical fiber that consists of excessive pace, big potential worldwide optical networks. To guard the net from protection assaults, numerous protection rules and strategies are applied on the network stack's specific layers. One of the layers in photonic community i.e., photonic remains to be an open place of studies due to a further safety layer in transmission structures. Optical code-division has been taken into consideration as an awesome measure to offer security of optical layer [93]. This is so because of the reality that if number of codes function concurrently, it might be nearly not feasible to achieve any effective records from the statistics sign. Yet, elevated complexity of optical tapping gadgets positioned in community and personal optical networks these days permit unrestricted way to types of communications and information that is being transmitted in either of the segments of fiber. The main motive of optical layer is to avoid the breaching of transmitted optical data from illegal ways, that means the encoded binary content will no longer be interpreted by the eavesdroppers or varied with the use of jammers.
3. A distinctive OCDMA technique network with N pairs of receivers and transmitters is depicted in Fig.1.16. Every individual transmitter comprises of a particular data source and a laser which converts the obtained signal form electrical to optical form with the help of a modulator, after that the optical encoder maps the search bits into high- rate optical sequences. As per the name, the OCDMA technique allots specific code to every single user to avoid mixing of users.

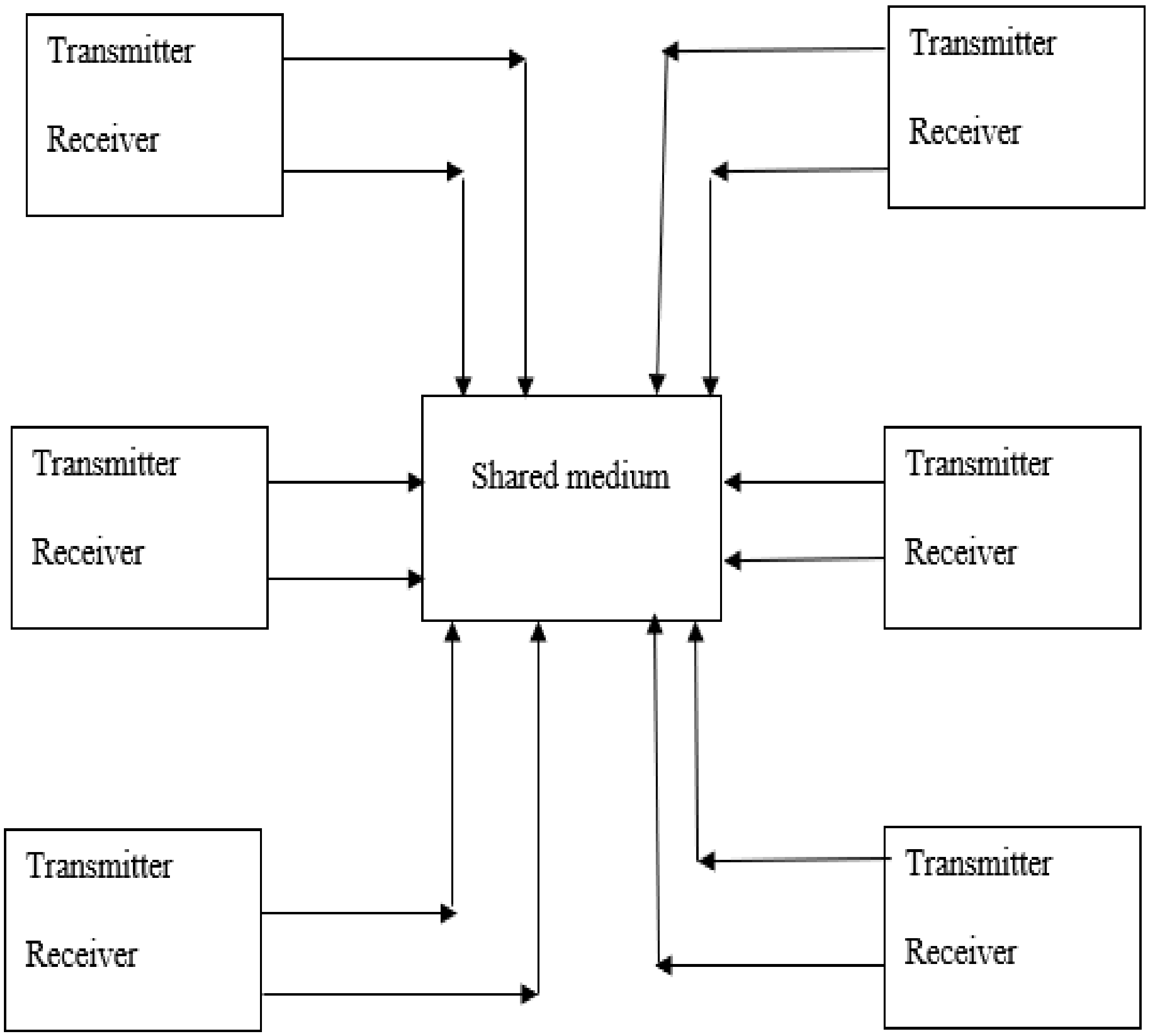


Fig. 1.16 Basic Block Diagram of OCDMA Network

1.8.3.2 SAC-OCDMA: A program based on the Zero Cross Correlation (ZCC) Code

The spectral amplitude coding technique comprises of the separation of multiple optical codes across a particular internal wireless system for different data levels along with the position of the receiver in the presence of ambient light. It is OW technology which imparts high speed communication and high security level while transferring of data. There is limitation named as MAI and PIIN when there is transmission by number of users at same time. Hence, the division of the access code is more accessible technology which is used in accordance with the zero-cross correlation (ZCC) code to minimize the disabilities that were present in OWC programs. The main positive aspect of ZCC code is the ability of the code to eliminate PIIN, thereby reducing multiple access interference [94]. Many research findings reveal that with a minimum error rate, there is ability of the system to efficiently perform at a desirable data rate. It also offers the best mobility in all the possible positions inside a room with a permissible signal rate.

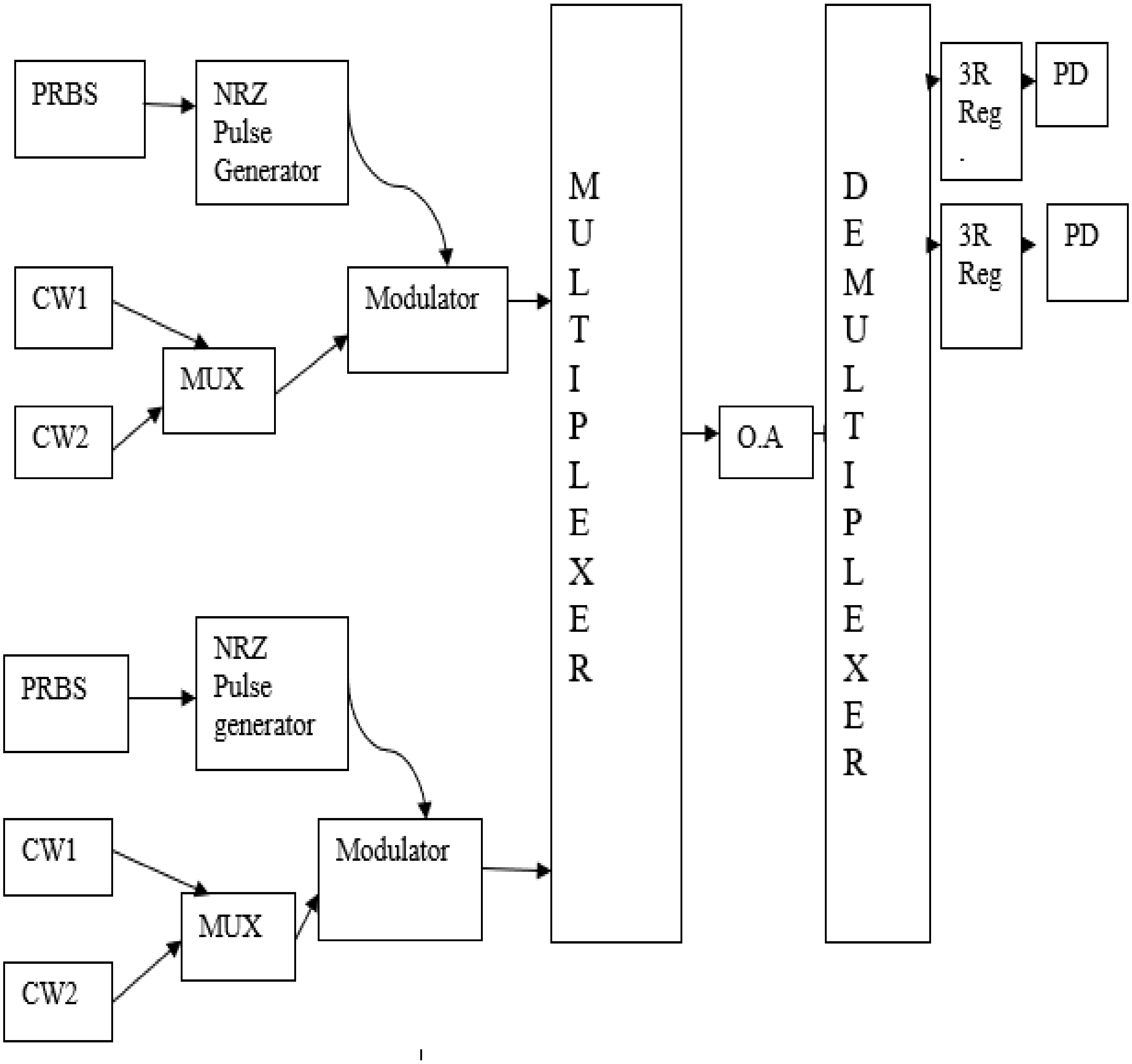


Fig 1.17 Diagram showing SAC-OCDMA system of communication

The system comprising of SAC-OCDMA technique has been widely examined owing to its numerous features over RF, like high level of security, easy set-up, electrically protected, electromagnetic interference disruptions, low bandwidth requirement, cheap price and free-licensed spectrum [95]. In addition to it, the visible light does not have the ability to penetrate the opaque objects like walls hence needs to remove other interferences between the consecutive rooms. It is noted that OWC networks are prone to multipath scattering, which leads to a moderate signal distribution Disruption (ISI). To overcome these disruptions that reduce system performance, a lot of promising technology is already used. Optical code separation technique is considered to be one of the efficient advance technologies employed in optical wireless communication, that has fascinated a lot of attention because of its ability to permit multiple users use the same bandwidth at the same time without utilizing any type of electronic speed data circuits which are required by virtual TDMA technique and many other type of access techniques [96]. It also has the ability to reduce the disruption of multiple accessibility which was present in OW programs, too provides maximum security while transmitting the data. With the usage of efficient set of visual codes, multiple interference access and phase intensity can either be removed or minimized. Fig 1.17 diagram showing SAC - OCDMA system of communication.

Table 1.1: Comparison among the commonly used Optical Multiple-Access Schemes

Multiple Access Technique	**Pros**	**Cons**
TDMA	➢ High Throughput ➢ Continuous Traffic ➢ Deterministic Access ➢ Dedicated channels	➢ Hard Limit on no. of Users ➢ System Wise Synchronous ➢ Not efficient in Bursty Traffic
WDMA	➢ High Throughput ➢ Constant Traffic ➢ Dedicated channels ➢ Time Asynchronous Access	➢ Limitation on number of Users ➢ Need Wavelength Management ➢ Inefficient in Bursty Traffic
OCDMA	➢ Efficient in Traffic ➢ Flexible User Access ➢ Time Asynchronous Access ➢ Normal limit on number of Users	➢ Collisions ➢ Random Access ➢ Performance degrades with greater number of users

1.9 Codes for Optical Communication

The OCDMA system comprises of two main categories named as coherent and incoherent. In coherent OCDMA scheme, for applying an optical code, the phase coding needs to be done of the optical signal, while in non-coherent OCDMA system amplitude modulated codes are used for encoding. Coherent OCDMA technique has the ability to support multiple users because of less sensitivity against the interference raised by the other users which are active [96].

There are mainly two types of optical coding schemes which include synchronous and asynchronous coding. Asynchronous coding facilitates simultaneous users to have accessing ability over the same optical transmission medium individually with zero wait time, coordination or scheduling, therefore making efficient use of the transmission medium.

A variety of codes [97] which are proposed for OCDMA systems are shown in Fig. 1.18.

(a) **1-dimensional codes** either spread in frequency or time in accordance to the encoding of the optical signal. The coding which is accomplished in the time domain by employing optical pulses of short duration is known as temporal OCDMA. Contrarily, coding either of the phase or intensity of a broadband optical data either by means of amplitude or phase masks is known as spectral OCDMA coding.

(b) **2-dimensional codes** spread both in time and wavelength simultaneously. The techniques like wavelength-hopping time spreading are type of a 2-D coding employed, where pulses are organized in non-similar chips across the bit period and every single chip is having a different wavelength [98]. The two-dimensional codes have the ability to offer more flexibility, grant high cardinality, better spectral efficiency, much securing and greater capacity than 1-Dcodes.

(c) **3-dimensional codes** are an extension of 2-D optical codes, where the optical pulses are spread in three different dimensions namely space or polarization, time and wavelength. A 3- d user code employs the two polarization states in accordance to the discrete wavelengths and chip times to individually find client such that every single code is efficiently orthogonal for sufficient auto-correlation and minimal cross-correlation. 3-D codes minimize the interception probability due to the additional dimension [99-100].

1.10 Mode Division Multiplexing (MDM)

One of the forms of electromagnetic wave is light wave which travels in the vacuum that is presenting the outer space. These waves are formed with the help of energy filled electric charges and are chosen in the form of transverse wave which has both a magnetic and an electric component. The conversion of non-polarized light into polarized is known as polarization. The feeding of various type of intensity profiles into the fiber is defined as mode division multiplexing (MDM). On the basis of electromagnetic behavior, there are different types of modes (hybrid and transverse) present as per the angle formation between the axis of transmission and the electric field vector.

When all the existing modes are grouped in one series then it is termed as Linearly Polarized (LP) modes that can be achieved by either of the cases (i) by varying the value of core's refractive index (ii) by altering the size of the core (iii) by varying the wave's wavelength (iv) by allotting a particular Eigen value. In case of optical wireless channel, it is not feasible to achieve the LP modes with the help of first and second parameter and it is possible only in case of optical fibre. Hence, to achieve LP modes, either the wavelength needs to be altered or the eigen value needs to be fixed.

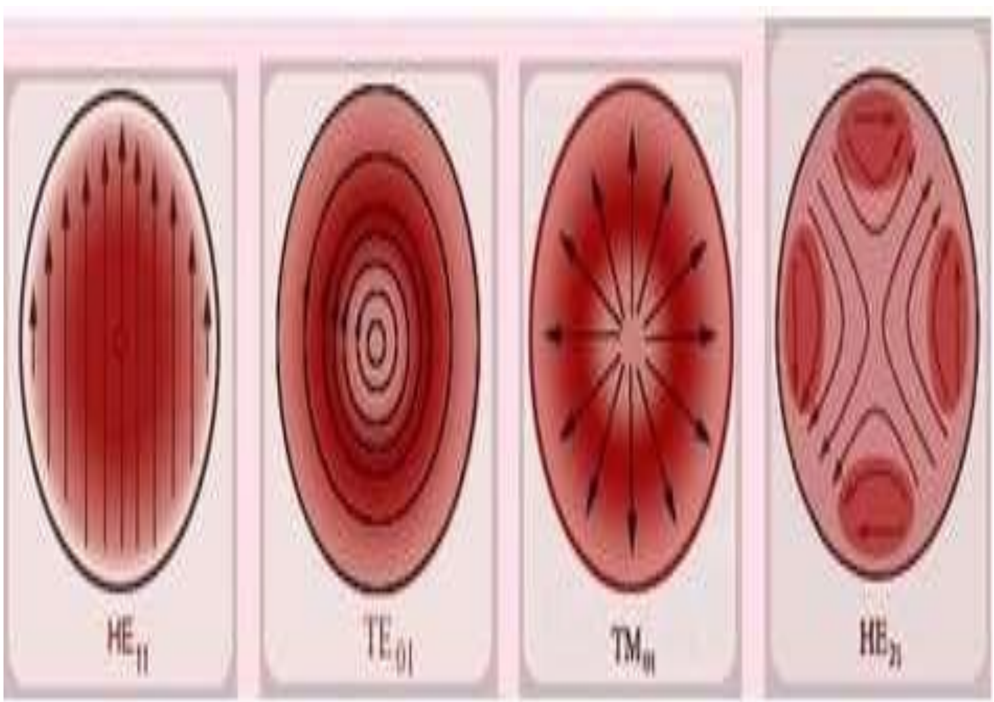


Fig. 1.18 Few Electromagnetic modes in optical domain [75]

The different types of EM modes of light are depicted in Fig. 1.18. It is noted from the figure as follow:

- HE_{11} mode comprises of E.F. that is always focused upward having highest value at the axis and its value decreases when we shift radially towards the outer ends. This HE_{11} mode has the lowest order of the mode.
- The transverse electric (TE_{01} and TM_{01}) modes comprise of circular shape symmetric E.F. The value of E.F. is highest in the center and the values lowers as we shift radially towards the outer ends.

1.10.1 Nomenclature and Indices of EM Modes

For identifying the field patterns from the two existing subscripts which are written with the mode, we need to consider the ordered pair i.e., ν, m. Here the value of "ν" depicts the nature of the electric field in the azimuthal plane, which means the change in the electric field w.r.t Φ. We can also define it as how many cycles have changed in the Φ plane. Further, the subscript "m" reveals the number of maxima, minima and the zero- crossings which took place in the azimuthal plane. It is depicted that number of zero-crossing is always one less than the index, i.e., "m".

Some observations can be made for the modes TE_{01}, TM_{01} and HE_{21}, and variations in the field can be foreseen from the data of the modes' two indices. It is observed that for TM_{01} and TE_{01} mode, the field present is symmetric and circular across the axis of the transmitting medium and even does not have any zero crossings in the azimuthal plane. It can easily be analyzed in the Fig. 1.19.

The above discussion reveals that EM fields are LP and transverse [101]. It concludes that the electromagnetic field comprises of the same intensity varying patterns yet all are polarized linearly along with same linearity which means that the polarization orientation is similar in case of all the present fields. The polarization can either be horizontal or vertical as depicted in Fig.1.20.

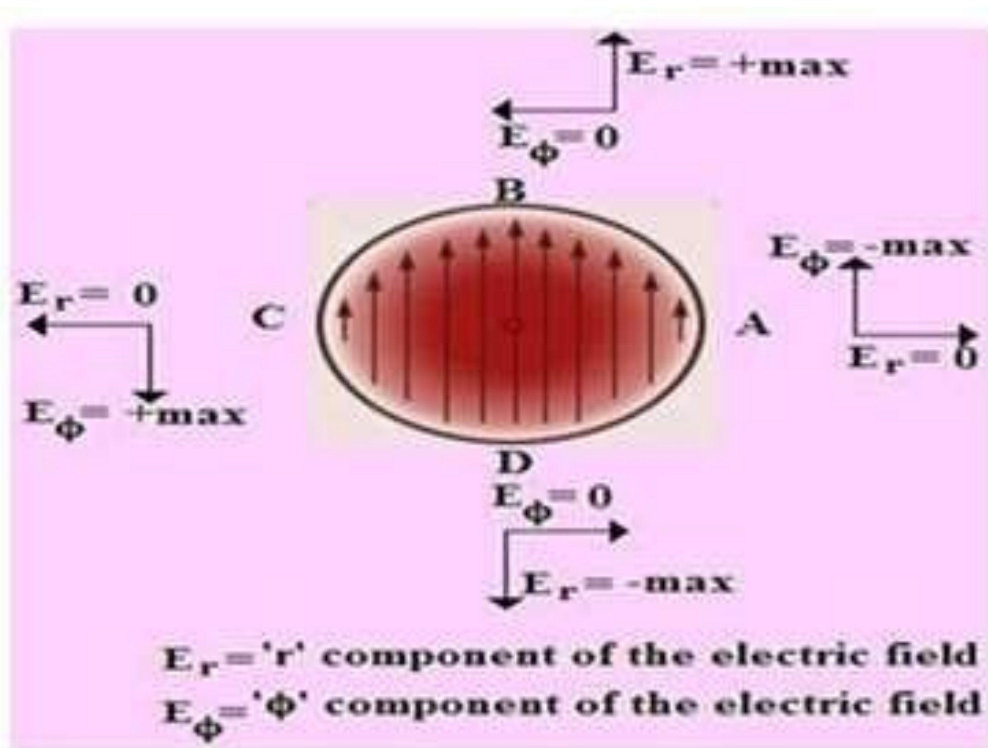
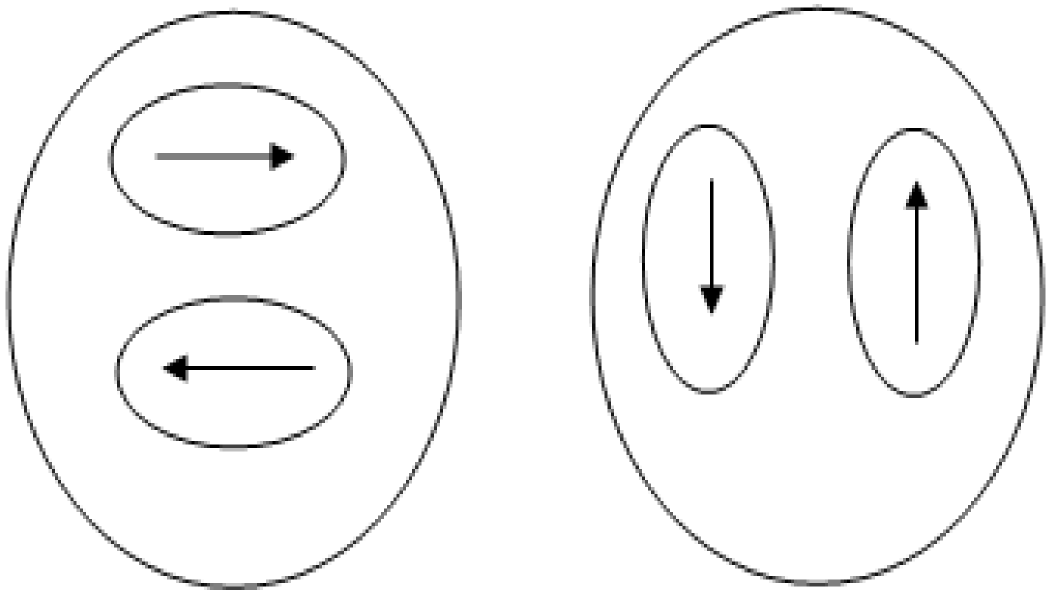


Fig. 1.19 Variation of the field components [101]



1.20 Polarization of the linearly polarized modes (Horizonal and Vertical)

1.10.2 Improved performance enhancement Using Hybrid SAC-OCDMA via the Is OWC channel

Spectral amplitude coding (SAC) OCDMA is considered to be one of the prominent schemes of OCDMA technique which is most investigated area owing to its special features such as high level of security, large capacity of network, and the flexible nature employed in sharing of channels without any sort of overlapping. Contrary, IS-OWC that is a good place for visual communication research is helpful in the explosion of long-term shipping and communication. In this, a SAC-OCDMA hybrid system via the IS-OWC channel utilizing a zero cross correlation code for advance intensity fluctuations set-ups is deployed. A block diagram depicting the SAC-OCDMA system is drawn in Fig. 1.21. To imitate the four users, the direct detection process is used. In the set-up, single laser source is employed along with advance modulation formats. The proposed model has three components, the transmitter, the channel and the receiver [102].

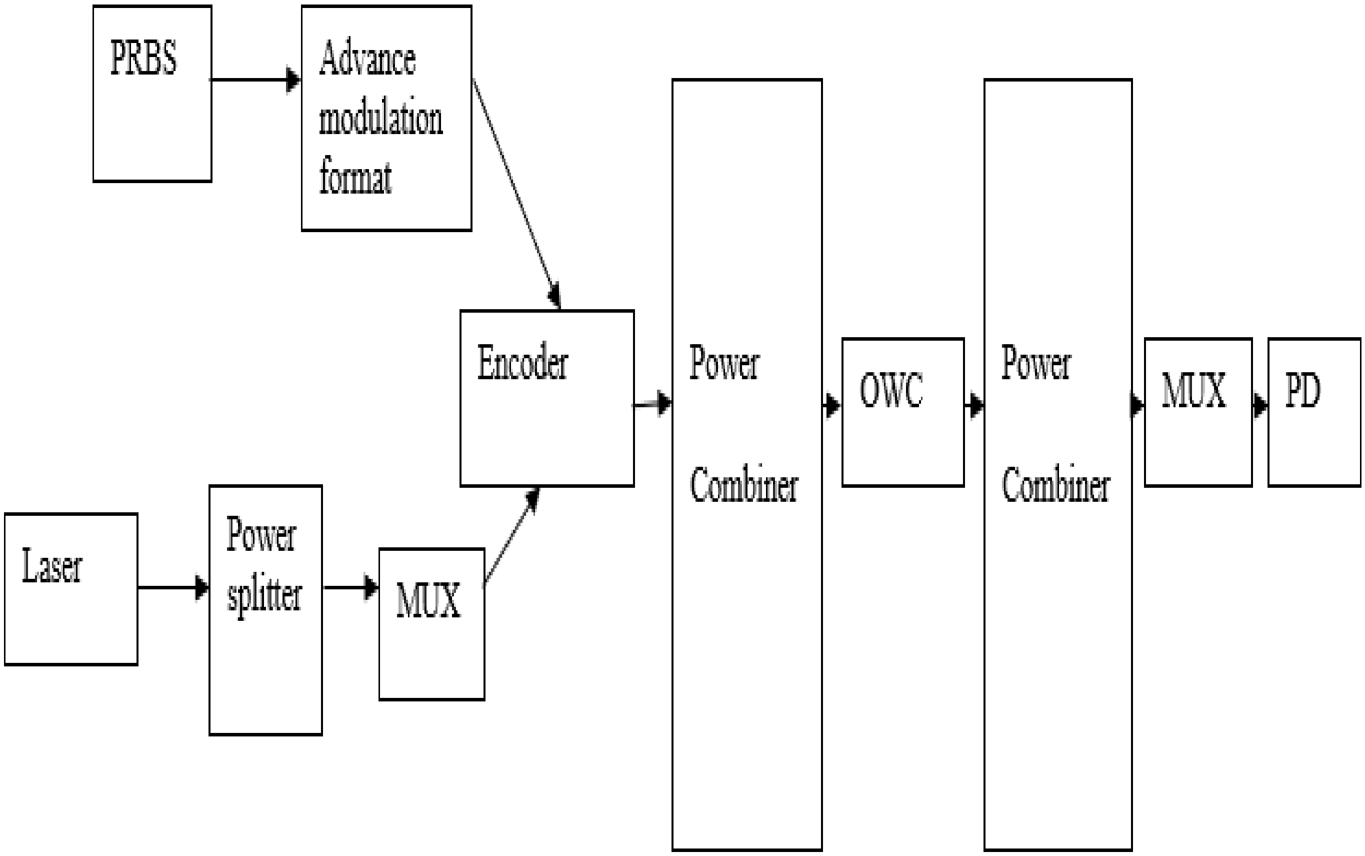


Fig 1.21 Diagram of SAC-OCDMA using IS-OWC channel

1.10.3 Zero Cross Correlation (ZCC) code

The ZCC code fall in the category of spectral amplitude coding OCDMA technique. It is considered as one of the best methods to enhance security and increase bandwidth efficiency. It has numerous benefits such as simple construction of code by using transformation method, as well as the opportunity to choose and natural weight of the code. In addition to it, the absence of cross correlation in it enhances the performance of the OCDMA based system by eliminating the multiple access interference. The ZCC code even helps to remove PIIN which leads to efficient system performance. Through using zero correlation codes, data rate can be improved in inter satellite OWC system.

For Optical based CDMA programs, coding is considered to be one of the most prominent parts to consider in a file. The designing of the ZCC code is done in such a manner that it helps to eliminate multiple access interference due to variability among various users and as a result is pressured by MAI [103]. The defining of ZCC code can be done with the help of a matrix named as K × L, where the K line denotes the user number and the code length is represented with L. Uni polar orders are employed for amplitude code, whereas source spectrum is defined as the code name. These types of orders match the K lines, further depending on signal that is transmitted, this order is completed. Fig 1.22 diagram showing system using OCDMA-ZCC.

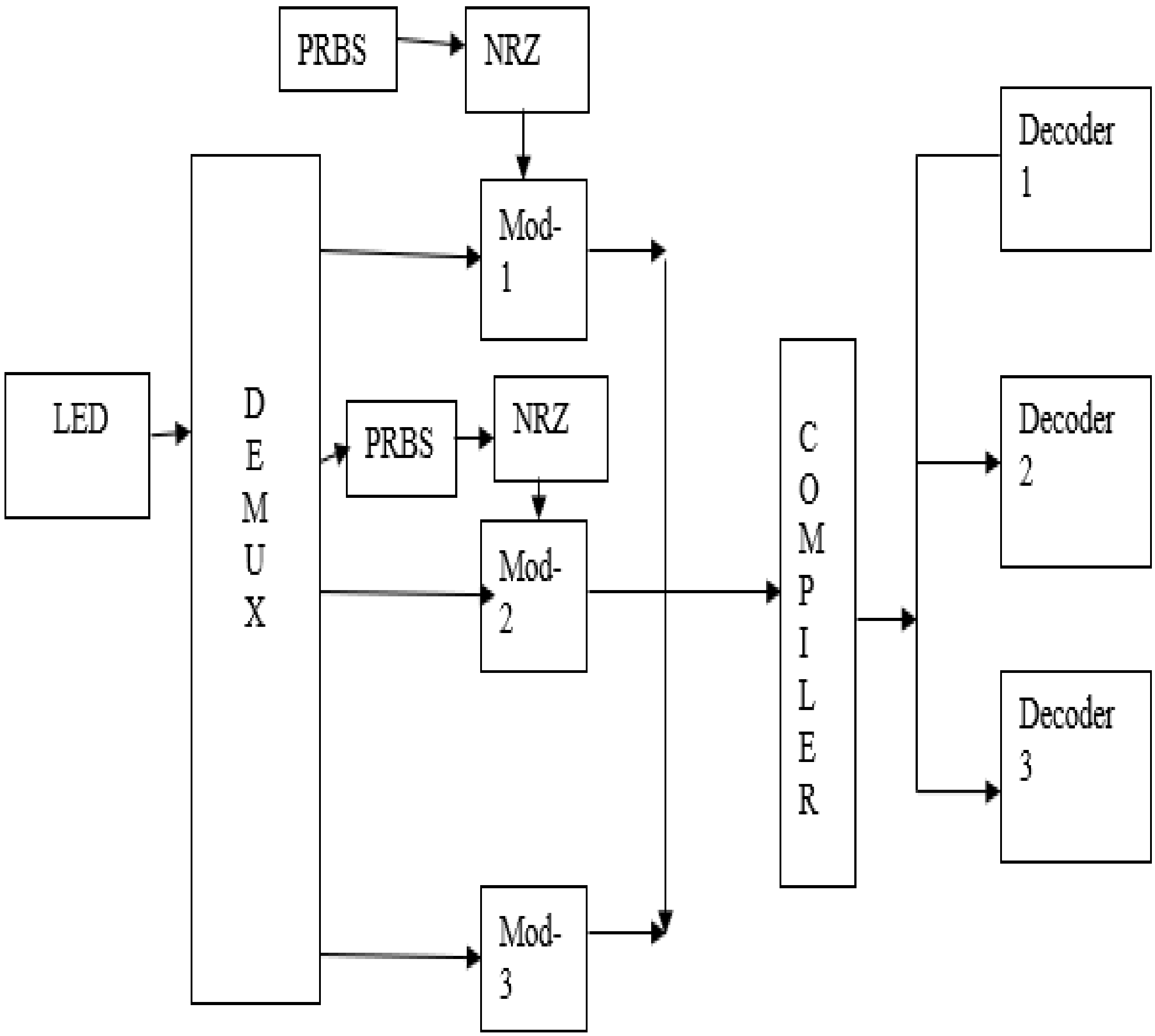


Fig 1.22 Diagram showing system using OCDMA-ZCC

1.10.4 Multi Diagonal Code (MD)

The MD code comprises of a simple structure based on the patented matrix, the flexibility of selecting i-code weight and user number, and zero integration assets. Fig 1.23 depicts the block diagram of FSO system using ZCC and MD codes. The data works well organized in the order of transmission by code with an external visual modulator. After that, the fixed code sequence is put together and transferred status of FSO. All spectra code must be transferred to save the file referring to the signature. On the recipient side, the sequence of separated codes is different. The decoder relies on the direct detection technique, when the clean chips are removed because the details are thought to be derived from the unrelated chips. To avoid distractions, the removal of split chips is done. Symbols are received by PN image detector. Eventually, the signals received at the receiver's end are filtered with a LPF to remove the unwanted content [104].

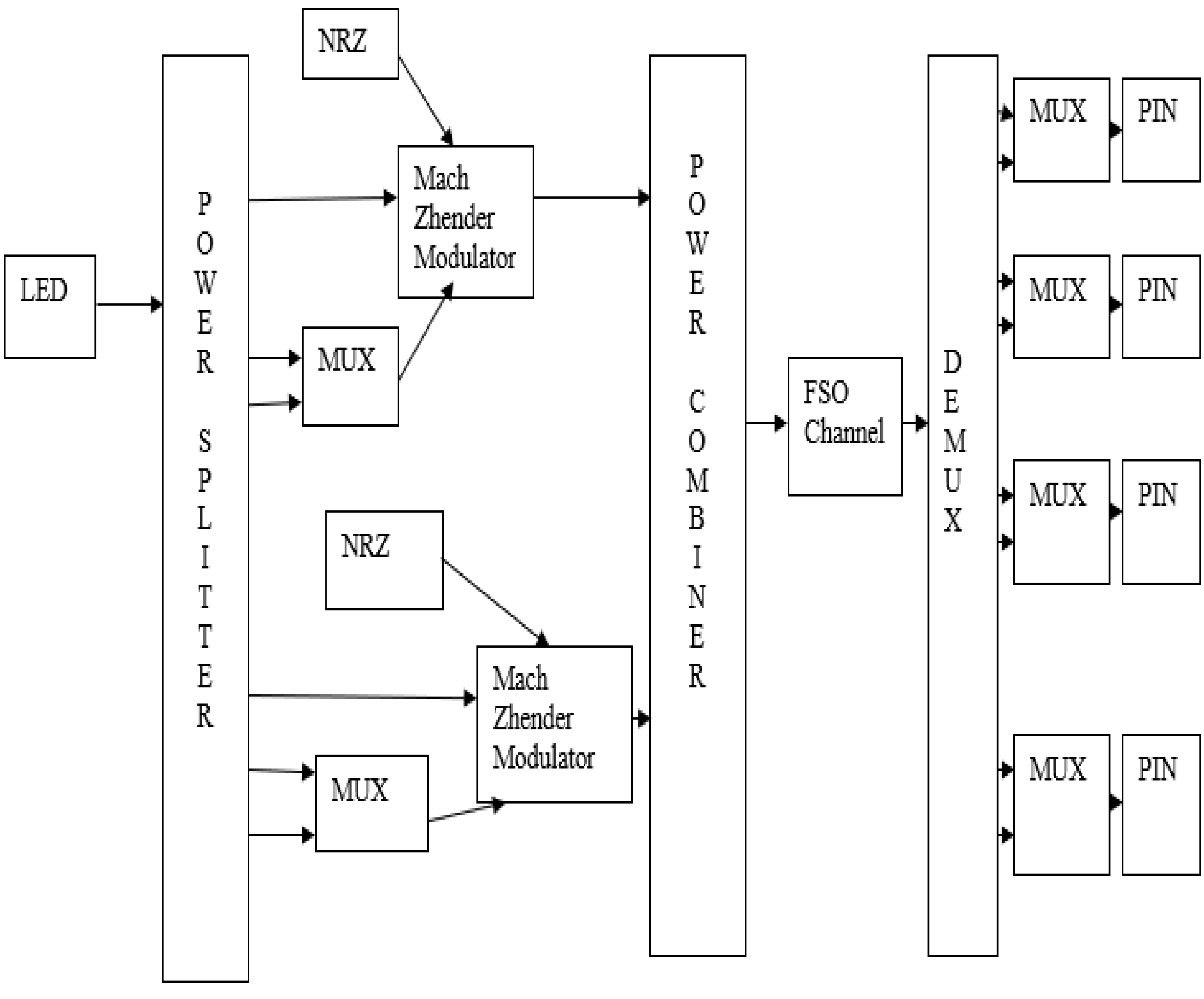


Fig 1.23Diagram of FSO system using ZCC and MD codes.

1.11 Polarization Division Multiplexing

Ever-growing wireless need in conjunction with the spectral lack of radio spectrum revealed the need to increase spectral efficiency, new integration voice fluctuations have advanced repetition techniques.

One optical process has been employed to enhance the efficiency of the visible communication systems i.e., polarization division multiplexing (PDM). The usage of PDM permits duplication transmission ability, as various signals can be sent over orthogonal areas having the same light separation [105]. Optical PDM employs the concept of transmitting independent signals independently above orthogonal separation having the similar optical wavelength. In optics field, the state of visual separation is termed as a state followed by a vector-field of light of transmitted light on a fixed plane. Line divisions are achieved only if the value of direction of the electric vector is same (the electric field is parallel with E_Z and Ey guidelines). If Ex and Ey are nine degrees out of the section, we have a circle separation. There is a split / left division of the right or left hand, depending on which side vector-field vector rotates, that is, when the vector-field field appears to rotate clockwise or counterclockwise [106].

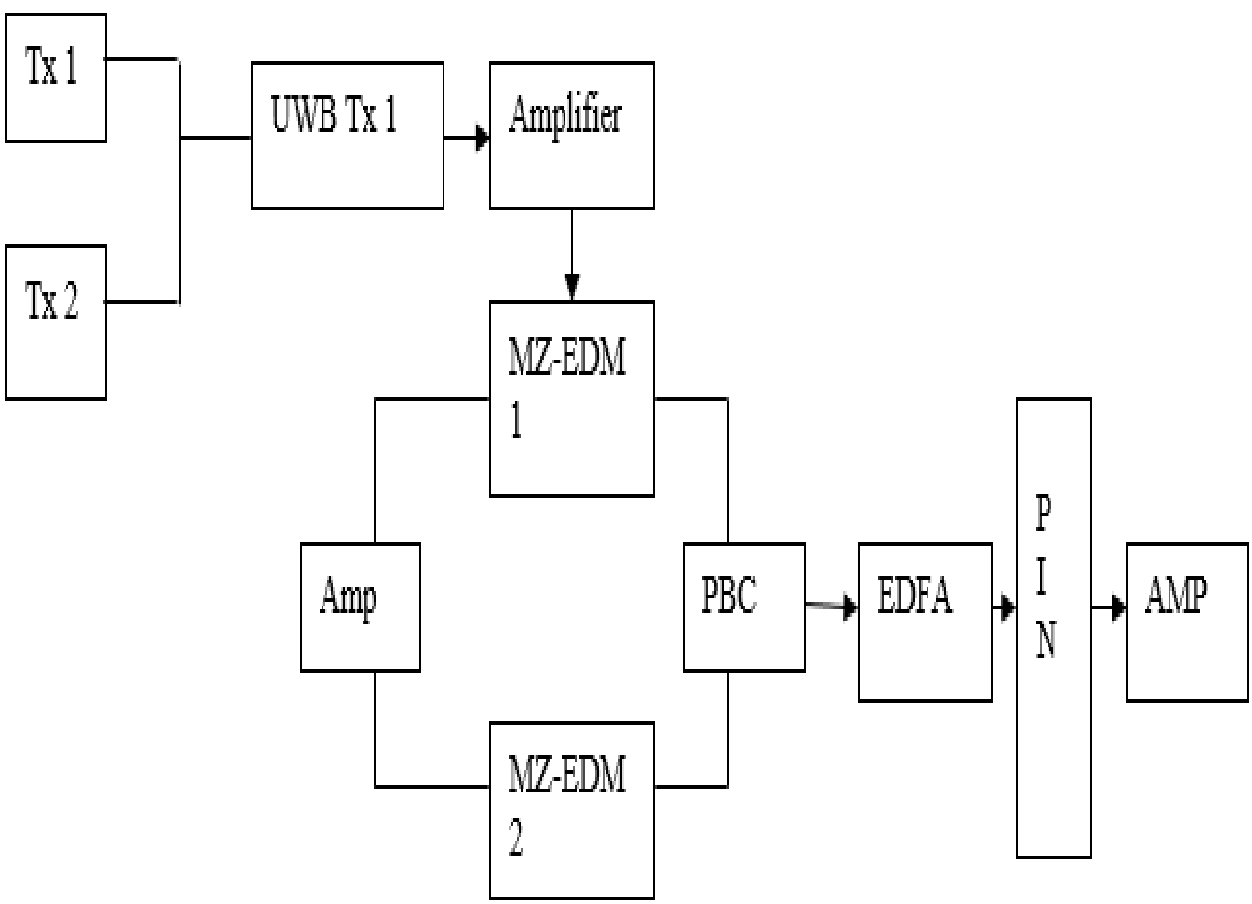


Fig 1. 24 Diagram showing SCM-UWB configuration using polarization methods.

Fig 1.24 represents the diagram showing SCM-UWB configuration using polarization methods. Use of polarization multiplexing for the combined distribution of UWB and WiMAX is proposed which indicates the transfer of different OFDM services for each orthogonal optical division. A single subdivision may be used to transmit WiMAX signals and orthogonal splits of UWB broadcasts. Multiplexed polarization power can be exploited again if large amount of frequency data is transferred across all segments, and even more if we use SCM to transfer many UWB channels. Analyzation to test the functionality of PDM optical passive network is done. It has the ability to transmit three different types of UWB channels (complete UWB band 1) in separation A in addition to three more UWB channels in polarization B having a variable SCM configuration. PDM has the ability to transmit independent signals independently with same orthogonal polarizations having visible wavelength that allows to replicate the bit rate and transmission of spectral efficiency. This transfer is made without any use disability compensation process or in-line rehabilitation sections in addition improvement can be achieved through disability compensation [107].

1.12 Conclusion

Wireless exchange which is verbally done is outstanding generation and has numerous blessings including freedom to person ambulatory everywhere beneath the network, low set up fee, dependable. Radio frequency changed into a true technique to address the problems that exist in stressed out mediums but after this communication has sufferings from limited bandwidth availability, small link reach, electromagnetic interferences, and many more. Inter-satellite tv for pc communication has limitations like low level of security, sign fading, and occasionally matching when RF was employed. But researchers confirmed a closing manner out to eliminate the shortcomings in RF conversation and named this generation as wireless optical communication. By using mild laser mild as a carrier and high data rate, immunity towards electromagnetic interference, excessive system capacity can be achieved with usage of inter-satellite optical wireless communication. Benefits, risks, precept, records of OWC transmission, exclusive earth orbits are elaborated.

The use of the SAC-OCDMA technology in inter satellite has numerous benefits like using greater number of users, improving security level, and enabling feature of flexible channel allocation. This thesis discusses the effectiveness of SAC-OCDMA program in both wireless communication scenarios concentrating on different type of minimal cross correlation codes. It has also clarified the effect of the value of cross-linking and interference has on the system performance. Limitation outcomes have revealed the effectiveness of the SAC-OCDMA codes. Codes comprising of zero cross correlation exceed the codes that have the lower junction of the cross. The ZCCRW code provides excellent performance with zero cross correlation in inter satellite. Also, MDM enhances the security level in the IS-OWC system which is considered to be the most important aspect in communication.

CHAPTER 2

LITERATURE REVIEW AND OUTLINE

2.1 Introduction

The rapid increase in the internet users is continuously demanding for improved information handling capacity in the concerned network regions. The requirement for efficient capability has increased notably which might be inspired through numerous programs inside the areas of internet browsing, video streaming, sharing of documents, smart hi-tech houses, video conferencing, and so on. Consequently, to meet with these demands, a number of new optical networks are explored at various levels [3-11]. In the literature survey, several multiplexing schemes have been recommended which employ wavelength, segment and amplitude such as DWDM (Dense WDM), 3-d OCDMA and WDM, coherence based spatial-section-time coding and many others.

In past wavelength department multiplexing turned into proposed and numerous troubles associated with implementation of WDM structures had been delineated within the literature. The wavelength solidity of space within channels, numerous wavelength MUX, DEMUX, sources and couplers result in number of the troubles which are discussed via distinctive authors [91]. The WDM technique permitted communication of forty channels with channel space of 100 GHz at 2.5 Gbps speed imparting a typical potential of 100 Gbps. Further, the WDM systems had been proposed with comparatively small channel space and it termed to be as optical FDM systems.

In OTDM scheme, a specific time slot adjustment is mandatory for the pulses which arise from different sources so that these pulses are properly multiplexed and timing is equally important for demultiplexing also. Therefore, the principal problem concerned with implementation of optical TDM system is lack of proper clock jitter and lack of effective coordination of clock especially at high frequency level like around 1 THz.

In [6], the authors analyzed the output of a 40 Gbps data rate wavelength division multiplexed passive optical community having 100GHz channel space and speed of 10 Gbps along with use of different type of filters at the receiver end to filter the unwanted content. Authors confirmed a three-dimensional spectral phase-time optical code division multiplexing scheme which employed 6 users operating at 5 Gbps and minimum usage of energy in every step. This design enhanced priority of a message and quick routing technique to increase the routing efficiency by keeping in consideration the effective transmission of information. They concluded that the gain version decreased from 2.01 to at least 1.15 Db efficaciously for the proposed amplifier of EDYWA hybrid type presenting a potential of ~1 Tbps. DWDM structures are impacted the most by the losses incurred because of cross talk, noise (pump's relative depth noise switch and Rayleigh backscattering) and different type of non-linearities. In addition to it, the digital type coherent optical fiber strategies are stated which employs PDM technique which almost increases the capacity of the channel to two times [100]. Yet the researchers are finding the spatial multiplexing multi-mode techniques to cope with the need of higher capacity as demanded by the society for various applications [101].

The MDM based IS-OWC is an attractive multiplexing area as it has the ability to offer reliable, flexible and speedy communication to fulfill the need of higher capacity and secured transmission. The IS-OWC system embedded with MDM and modulation techniques has been of great interest owing to its ability to support number of modes, enhance potential of multiple users and minimize the bit error rate [101]. On the premise of those problems the inclusive literature survey and limitations in gift look at are defined in the below sections.

2.2 Literature Survey

The major research in the field of MDM came into an effect around 1982 however up to 30years, the authors didn't take much interest in this novel idea [41]. The basic test in this field covered an area of 10km by employing three different spatial modes by modulating them at 14Gbaud inbuilt with PDM-QPSK technique. Later on, a number of advancements originated. The distance covering capacity reached up to 96km by employing 3 different modes and it efficiently delivered 5 spatial modes across 40kms [42].

Amphawan [104] demonstrates an innovative MDM architecture to overcome the limitation of frequency availability. The performance of optical MDM of donut type mode is investigated using power coupling coefficient distribution. The different modes evaluated are: Hermite-Gaussian (HG) and Laguerre-Gaussian (LG) mode to further realize 4x 20 Gbps transmission. The results achieved have high SNR, power coupling coefficients and received power for distance upto 50km, 30km, 20km and 40km for different 4 channels respectively. Few of these are elaborated below.

2.2.1 Mode Division Multiplexing issues

Many authors furnished their views on outcomes of linearly propagating signals in multimode fibers. The coupling conditions and models were analyzed. The different parameters such as losses based on mode and modal dispersions are taken in to consideration and worked upon. These parameters impact the channel capacity and the design of MDM based IS-OWC systems. It was concluded that proper coupling and coding technique enhances the channel capacity along with minimization in the losses incurred due to mode dependent loss (MDL).

Rademacher et al. [105] analyzed a noise Gaussian kind to calculate the non -linear value in spatial devices and value of OSNR. They combined the logical results with the output based on FMF, where spatial modes ranged from 3 to 6 and excellent results were attained amongst all.

Antonelli et al. [106] depicted the main features responsible for nonlinearity in SDM transmission when effect of mode coupling was observed randomly. It was reviewed that the modal dispersion decreases the impact of intra- channel disturbance among the modes. Further, values revealed that for the practical values of modal disturbance the obtained output shows dependency on the specific MO, therefore hindering the usage of techniques based on back propagation.

Schmidt et al. [108] investigated a particular kind of modes and it's strong coupling in non-linear multimode fibers. The results revealed that the nonlinear values are not impacted with the mode analysis. They found the LP field distributions and particular vectored modes consisting of defined difference mode solving. The analytical results are collected and validated with the simulation output.

Ho et al. [109] examined the capacity of the channel of MDM based system consisting of MDL theoretically. In presence of efficient mode coupling field, the loss caused due to modes may be defined as Eigen cost distribution in small MDL locations. It was analyzed that maximum mdl for 2 modes was approximately 23.4 dB and 80 dB for more than two modes.

2.2.2 Architectures Based on MDM-OCDMA

Yang et al. [11] developed a new scheme for SAC-OCDMA system named as multi code keying in which users were allotted different signature sequences to achieve an efficient spectrum. The usage of shifted prime codes is favorable for this scheme because with the help of prime codes' patterns compact encoded and decoded structures can be implemented easily. The outcome showed that multi code keying scheme had enhanced spectrum efficiency as compared to two-code keying provided the number of code words for single user is more than two.

Leaird et al. [12] validated a new modulation format- spectrally phase encoded OCDMA on the basis of switching among two codes. The security feature is enhanced up to greater extent in the proposed OCDMA method as compared to on-off keying due to elimination of exposure to eavesdropper due to employment of simple energy detector. Although this research doesn't prevent the vulnerability to eavesdropping methods that consists of different architectures in signaling and coding techniques.

Salah et al. [15] studied how various codes (Enhanced Double Weight (EDW), ZCC, Random diagonal (RD), and Modified Double Weight (MDW) performed in SAC-OCDMA. The codes are evaluated in terms of data speed and fiber length to study the effect of MAI and BER when 3 users are employed for simulation. The findings show that due to absence of cross correlation, ZCC is superior among the suggested codes followed by RD code. The MD and EDW codes have non-zero cross correlation properties.

Ashour et al. [17] reviewed the WDM based OCDMA systems along with other hybrid WDM/OCDMA systems with one dimensional code. Recent security features and coding techniques employed in optical fiber communication are discussed. The results revealed that in OCDMA and WDM users can be transmitted on same spectrum by employing different codes and also obtaining data security. The author explained the hybrid OCDMA-WDM scheme that can be used in further research areas.

Naresh Kumar [23] had presented 2.50 Gbps optical wireless communication system in HAP-to- satellite links using PPM modulation schemes which is important application of FSO-OWC technology for future usage. The analysis of 2.50 Gbit/s OWC based system by employing PPM modulation technique over a path of 2500 km was presented with BER 10^{-6} in HAP to satellite links. It is concluded from the results that electrical and optical SNR decreases with the increase in transmission wavelength and electrical and optical SNR increases with the increment in receiver aperture and transmission power.

Vishal Kumar et al. [24] had presented different challenging issues for an IsOWC system to achieve prolonged inter-satellite links to tackle with the degrading factors to achieve high speed IsOWC system with minimum BER. It was examined that the satellite movements and vibrations are the major challenges for alignment between transmitter and receiver. It was recommended to use different modulation techniques, small divergence angles and diversity techniques.

Singh et al. [26] discussed the security level of spectrally encoded OCDMA technique by employing two-dimensional modulation format. As compared to existing on-off keying method, the proposed code-switching technique simultaneously improved the security and system capacity. Further, the results revealed that security is enhanced at higher data rates along with minimum bandwidth requirement even for multiple users. For every 30km fiber length, a data rate of 10Gbps is obtained for single data format.

Singh et al. [27] had explored the impact of bit rate on distance of the channel. The investigationon WDM -OWC system with 8 channel is performed. The channel spacing of 100 GHz and wavelengthrange from 193.1 THz to 193.8 THz were considered here. The four values for bit rates were taken namely as follow as 0.008, 0.08, 0.8 and 8 Gbps and conclusion was drawn that low bit rates should be used to achieve transmission over longer distances. In this model the author investigated that error-free communication(BER < 10^{-9}) is achieved at a link distance of 11,500km for a bit rate of 8Mbps and 2100km for bit rateof 8Gbps. With 50cm aperture diameter, non-error communication was achieved till 22,500km.

Patnaik et al. [28] proposed an ultra-high bit-rate Is-OWC) system in which LOS setup along with coherentoptical quadrature phase-shift keying (QPSK) modulation scheme is used. The system efficiency is analyzed at operational wavelengths i.e., 1064 and 1550 nm by taking BER, quality factor and eye opening into consideration. By incorporating input power= 30 dBm, the distances observed for a bit-ratesof 100,160 and 400 Gbps are 9532, 7542 and 4767 km respectively.

Noor et al. [29] did the experimental assessment of number of transmitters and receivers on FSO basedlink. The quality of the free space optics system can be enhanced by employing multiple transmitters andreceivers FSO based links. The FSO link performance is determined by the power received at the outputwhich is theoretically calculated by using the established equation. Then the calculated theoretically values of received power are compared with experimental values to determine its correlation.

Noor et al. [30] discussed performance outcomes of FSO based link with number of transmitters/receivers. The relation between the BER and the power received at output is analyzed and calculated experimentally for multiple numbers of TXs and RXs.

Revathi et al. [31] examined the efficiency of WDM and SCM systems by employing various modulationschemes. The performance of 4 channel WDM and SCM systems SCM system is investigated.The performance analysis of SCM employing OSSB (Optical Single Side Band) has been studied by using three different modulation schemes. It is investigated that the signal with minimum bandwidth cantravel longer distances with relatively low amount of dispersion.

Liu [32] analyzed the optimization of satellite laser communication subject to log-square-hoyt fading. Onthe basis of the results obtained, a model with certain optimizations is proposed to reduce outage probability, in accordance with the power of transmitter i.e., the input power by varying parameters of thesystem like gain of transmitter etc.

Wang et al. [33] discussed 4×12.5 Gbps speed WDM based OWC system. In this article, a 4×12.5 Gbpsmobile communication set up is shown efficiently consisting of error-free data at receiver. The four channels consist of range varying from 1550.12-1552.52 nm with an allotted spacing in channel of 0.8nm(100 GHz). In this each channel has bit-rate of 12.5 Gbps.

Qin et al. [34] presented M-code keying based on OCDMA set up consisting of parallel encoders to examine the systems' security. To reduce the searching time, a formula for same is derived that also increases the system's capacity M-fold and it employs same number of users. Here experimentally the application of differential phase shift keying OCDMA technique to overcome the limitation of unwanted noise content is investigated. A comparison was done with existing OOK-OCDMA scheme that revealed better sensitivity and security, easy receiver optical threshold and dynamic threshold setting required. It was observed that DPSK-OCDMA is practically more feasible than the existing techniques.

Sodnik et al. [35] discussed the achievements in Is-OWC system that are defined as per the technology developments. The first optical based Is-OWC of world was introduced in 2001 (between the SPOT-4 and ARTEMIS satellite), which proves that OWC technique can easily be acquired in space with reliability. In 2006, one of the Japanese Agency established two directional inter-satellite optical link between ARTEMIS and its Test Satellite, further in 2008, the German based Space Agency named as DLR presented a link between the near-field IR experiment and Terra SAR-X satellite which utilized the laser communication of second generation. In this article, discussion of the coherent laser communication systems since1989 is done.

Rashid et al. [36] discussed the quality and types of security that are cited to be the most important feature of OCDMA technique. In this article, comparative analysis of security for OCDMA signaling is done that employ wavelength hoping and time spreading. The probability of correct data estimation is calculated by considering different factors like SNR and total system capacity. It is depicted that complex code results in high SNR whereas transmission of more than 100 bits lowers SNR value. A comparison is made with cryptography and it is evaluated that security feature depends on system architecture and the simulation parameters.

Noor et al. [37] had done the analysis of a number of receivers and transmitters and receivers as per the performance of free space optic link. Multiple transmitters/receivers in the FSO system provides a viable and optimal solution in case of FSO vulnerability towards atmospheric conditions. The results are carried out to analyze the performance for the free space optic link with respect to the received power, link margin and geometrical losses by employing mathematical relationships instead of different conditions of atmosphere. The simulation results show a substantial progress in the optical link with no effect on the condition of atmosphere.

Kemih et al. [38] optimized the aperture of transmitter by driving a genetic algorithm in optical satellite. It had also been found that BER increased because of the vibrations of beam pointing set up and impacts on the communication due to which communication between two satellites got jammed. The wide beam transmitter satellite may sometimes miss the satellite at the receiver side due to these pointing vibrations. So, transmitter with narrow beam divergence angle is beneficial to avoid this problem.

Younga et al. [39] demonstrated a WDM for transmission with high data rate over a 150 km optical link. The configurations include single channel with data rate 2.5 Gbps, single channel with data rate 10 Gbpsand4 WDM channels with data rate 10 Gbps. The WDM transmitter channel had 1556.1, 1556.6, 1557.2 and 1557.6 nm wavelengths. The four channels are multiplexed with a 1×4 directional coupler to maintain the polarization and encoded them with a PM electro-optic modulator (EOM). In this research values for losses in frame synchronization, data obtained on the received power and bit error rate was recorded.

Guelman et al. [40] examined acquisition and pointing control for inter-satellite laser communications. A unique technique includes pointing control system is implemented for an inter-satellite laser communication link. The same laser is used for both a transmitter and a beacon. The traffic capacity of the link is maximized by controlling the beam width from broad to narrow. The pointing control system must be precise to establish the laser link between the satellites and to maintain that link.

Pfennigbauer et al. [41] investigated the free space light broadcast stream using FSO links that introduced the bright light installment on broadcast communication links. The discussion of the reduction of land masses when sending data into space with high data rates has been done. In addition, to calculate the Q-factor in atmospheric turbulence as a haze and fog with a link rang distance. Here again discuss how to protect the network carrier and send relevant data without being affected by any disruptions in space. In this system to increase the size of the horns to transmit long-distance data link is required in quantum cryptography.

Su et al. [42] illustrated the key technology, separation of polarization modulation (PM), which should be considered when performing a standard wireless optical communication (OWC), also known as free-space optical communication (FSO). We analyze the distortion of the state of the earth's fragmentation as the laser beam disperses through the space station. The floating extent of the visual separation was estimated and the need for research on the proposed technology was discussed. In addition, we made comparisons between a PM-based FSO system and a switch-based FSO system.

Mostafa et al. [43] analyzed that the performance of SAC-OCDMA depends on the medium. On investigation of different codes, results revealed that MD code provided best performance followed by ZCC code in both OFS and FSO media. Further, RD code gave better result in OFS as compared to KS code that outperformed in FSO medium. They also studied the QoS, security features proposed system. The codes with low integration such as RD, MD and ZCC are employed. In the case of free space optics, dangerous weather variations and moderate disturbances are taken into account. In case of optical fiber system, non-linear effects, weight loss and distribution are considered with consideration. Further, the effectiveness of different codes was tested under various rainfall conditions of reduction. The simulation results revealed the performance of SAC based OCDMA codes is dependent on the media. It is analyzed that the ZCC code outperformed than the low integration codes in either of the cases that are free space optics and optical free systems. It is followed by the MD code which also performs good in either of the cases. The performance of RD code is better than the KS code performs in OFS system.

Alyan et al. [44] investigated spectral amplitude coding, fragmentation of multiple optical code access SAC based OCDMA over an internal wireless system for different data levels along with the position of the receiver in the presence of ambient light. It is OW technology which imparts high speed communication and high security level while transferring of data. There is limitation named as MAI and PIIN when there is transmission by number of users at same time. Hence, the division of the access code is more accessible technology which is used in accordance with the zero-cross correlation (ZCC) code to minimize the disabilities that were present in OWC programs.

Lui et al. [45] presented a novel ZCC code to minimize MAI and improve BER performance in SAC based OCDMA set up. The formulated code has simple and flexible nature where the variations can be done without complex calculations. Here the direct-spectrum spectrum signal is widely used in the ISL to navigate the constellation whereas the detection is a disappointing task because of the relative movement among the satellites. Signal search (code category and network company frequency) is performed using Fourier-divided variables (FFTs) determined by processor memory. The stiffness of the carrier is damaged by the rotating rotation. To solve this problem incompatible integration is done. It is because of the square loss that the acquisition response is reduced. The process of traditional integration that is not consistent with the process of integration is compensated. Numerical results show an improved sensitivity to detecting weak signals and keeping accounting costs at 60%.

Sarangal et al. [46] focused on enhancing the security of SAC based OCDMA set up with employment of two-dimensional modulation system. The formulated approach not only improved security but also increased the system capability. It was observed that hybrid technique minimized eavesdropping along with usage of lower bandwidth and high data rate. In addition to it, the proposed technique was compared to the existing OCDMA schemes.

Upadhyay et al. [48] designed cost-efficient SAC-OCDMA system based on MDM scheme to support upto 100Gbps data transmission. Random diagonal code is used for OCDMA based system and modal multiplexing of HG modes is used for MDM. The comparison shows that few modes fiber has better BER value in comparison to multimode fiber. Even the HG modes (01and 02) are converted into LG modes on the receiver side. The transmission capacity is almost doubled in the proposed system when MDM scheme is used.

Nisar et al. [50] introduced a novel technique by using Pascal's triangle pattern to design ZCC code for SAC-OCDMA. The key feature of the designed code is availability of simple code construction, desirable code length and flexible nature in selection of code weight. Eventually, the results reveal that proposed code has improved code length as compared to the older codes like OOC, MDW and MFH. Also, this code can employ a greater number of users in contrast to optical spectrum CDMA codes.

Bhanja et al. [54] proposed two novel (MRDC and MNZCC) codes comprising of zero to one and zero cross correlation respectively. The codes offered minimum bit error rate with respect to data rate, users employed, code weight and the cross correlation. On comparison with the prevailing codes, the system exhibited best results when the MAI and PIIN is negligible.

Kaur et al. [56] focused on the comparison between the achieved OCDMA research and the latest areas to analyze the positive aspects and drawbacks in the particular area. For switching to optical code networks, many noteworthy aspects were discussed and experimental research was performed by keeping in mind the commercial benefits of the prevailing CDMA. Eventually, OCDMA based systems outperformed than the WDM and TDM in terms of internet networks. Further, various SAC are discussed by reviewing factors such as modulation techniques, ER, BER, SNR, decision algorithms etc. Also, the positive and negative aspects of SAC were analyzed in terms of encoding decoding and future scope was overviewed.

Fouli et al. [57] surveyed the recent development in OCDMA and optical codes. The application areas of both are compared likewise optical coding carry information from network level. There are certain trade-offs when stating any particular feature of the technology like light source is inexpensive but dispersion and BER limits its usage for longer distance. Therefore, in this article in-depth study of each component and technique is done.

Jyoti et al. [61] analyzed improved security feature in OCDMA by incorporating spectral encoding based on code-switching technique. The security level was observed with the help of eye diagrams and obtained signals by considering different cases. In previous codes such as on-off keying technique, the intruder used to easily detect the data. Hence, to enhance the security level, code switching technique was employed. The results revealed that eye diagram was in the form of a noise signal at the intruder end and presented a proper eye diagram at the receiver side. Therefore, the proposed code had invulnerability against eavesdroppers and further just like other OCDMA techniques, the authenticated user can decode the original information provided only particular user is in present state.

Kaushal et al. [63] examined that the FSO communication has greatly enhanced due to its distinctive properties: high bandwidth, large data, fast transmission ability, low power, free licensing spectrum and quantity requirements. In addition to the FSO's excessive communication power, performance restrictions have adverse effects (i.e., absorption, distribution, and noise) of the space station. The main limitation observed among the main three deficits is atmospheric disturbance leading to small errors in the communication. The different shortcomings are being faced by the FSO communications system for satellite-to-satellite link, ground-to-ground link and satellite-to-ground link. The facts of employing optical backhauls is based on the space to provide low value of backhaul and high value of volume.

Bazn et at. [66] made a comparison to analyze the 2D time wavelength OCDMA set-ups at two different layers- data link and physical layer by taking various noises into consideration. Two different factors are taken into account namely MAI and beat noise (BN). A specific method is for comparing the two-dimensional codes is adopted by taking single column or row and multiple column or row. The output showed that BN depended on different code features and distribution of frequencies. Therefore, various characteristics are discussed which eliminate the BN impact.

Kaur et al. [69] developed a new ZCC diagonal identity matrices code and compared it with EDW code. The author highlighted the importance of OCDMA to cope with the ever-rising requirement of high rate of data and various users. The comparison is done on the basis of Quality factor, bit error rate, ER, eye height and SNR. The investigation was carried out by taking 7 users simultaneously with bit rate of 30Gbps. Also, mapping free scheme was employed for OCDMA based SAC codes that allowed the service user to support many users and design different codes for the selected users. This novel code is better than the prevailing codes as in this code there can be any count of users. The DIM code outperformed the prevailing codes owing to ZCC property.

Bakarman et al. [77] modulated semiconductor-based lasers that exhibit a variable wavelength chirping which arise from variations induced with gain of the laser RI. The impact of laser chirping is investigated when multiple Gbps light wave set up is operated at 1550nm wavelength. The models compatible with computer aided interpretations are employed to analyze the dynamic impact and transmission of chirped optical pulses with a SI single mode fiber. To evaluate the value of BER, a Gauss quadrature method comprising of train of truncated pulse is employed at the receiver end. This method allows effects of pattern because of non-linear optical power transmission and laser dynamics which need to be part of the designed model. The impact of system parameters and modulation on the output portion are analyzed. Panda [84] developed a new SAC-OCDMA based code with ZCC to reduce MAI and make it a more secure system. The code parameters (cross correlation, code length and user number) can be altered easily and the user number is varied with no increment in code complexity and code weight. Also, this code maintained BER value below the defined threshold i.e., 10^{-12} at received power value of -12dBm.

C.Y. Liu et al. [110] designed and demonstrated experimentally 320 Gbps SDM FSO channel. The link comprised of 8 channels and covered 100m distance. A notable eye diagram and minimal BER values are achieved by employing LNA and data recovery at the output end. The purpose of high data rate foe long distance is fulfilled in the proposed set up.

Gupta et al. [111] presented 6x6, 5x5, 4x4 and 3× 3 optical based MIMO-MDM multimode fiber set-ups with the help of inline- multimode, boost multimode, and pre multimode EDFA method. The obtained results were compared on the basis of BER and Q-factor. It was concluded that inline-multimode configuration provided best output for all cases of MIMO MDM with a coverage distance of 100km and tolerable bit error rate 10dB which eventually enhanced the performance of the proposed system. It also studied modeling a type of sensor that is distributed through fiber optics (containing a polymer metal binding) to identify pipe rust.

Shah et al. [112] surveyed the value of security and about the tools related to security. Also, drawbacks faced in the satellite communication during installation of security techniques were discussed. It is true that in different areas such as navigation, military, weather forecast, broadband internet and digital video there is requirement of satellite communication. There were numerous limitations faced during the transmission like lack of power control, long distance, high BER and security concerns that need to ne looked on. Eventually, the forthcoming research areas were analyzed and tools to be used were optimized for efficient performance in the field of satellite communication.

Bhanja et al. [113] proposed a novel 2-d MD prime hop code which exhibited zero cross correlation property resulting in MAI in optical fiber network. The output showed that the formulated code is able to support multiple users simultaneously with low BER and high quality of signal. In addition to it, higher security level is achieved at a particular layer with the help of a novel code and circuit diagram to overcome the issue of eavesdropping present during the communication.

Bertarini et al. [114] thoroughly studied OCDMA technique consisting of spectral phase encoding based on Walsh-Hadamard code. The objective of this research comprised of investigating a novel code set for enhanced security and least crosstalk. The results revealed that presence of minimum number of codes can cause crosstalk, so to overcome this drawback, an algorithm was proposed. The suggested algorithm aims at code sets that result in least BER for particular number of users. The novel algorithm helped to select the optimal code set irrespective of the active users and type of code family. Further, proved that large fraction of the present code sets didn't have high BER and crosstalk.

Ahmed et al. [115] focused more on codes consisting of desirable code length and ability to mitigate PIIN and MAI effects. A novel code named as DEU comprising of proper phase cross correlation was proposed in this article. In this proposal, four different odd even sets of DEU code were created on the basis of users and weight of a particular code. These different combinations not only increased flexibility but also outperformed than the existing codes. The numerical analysis revealed that suggested code performed better and supported long distances during point to multipoint communication.

Ahmed et al. [116] developed MDW code comprising of NAND detecting technique to depict the performance of OCDMA set up. Different system performance factors like noises and MAI were taken into consideration and it was noted that in contrast to AND subtraction and complimentary technique NAND technique supported more users with enhanced system performance. Furthermore, high BER was obtained with the help of simulation.

Khalighi et al. [117] demonstrated an efficient OCDMA network by employing SPECTS method. In this network, time division and polarization multiplexing techniques were employed which supported 32 users simultaneously at a rate of 10 GB/s. Further, non-linear thresholding and time gating helped to achieve user detection and reduce MAI. In few cases, implementation of FEC reduced the performance loss caused due to interference and BER noise resulting in power penalty of 10/user. The network comprised of minimum bandwidth requirement in decoders and encoders leading to nearly 50% high spectral output.

Donner [118] proposed a code to overcome the limitation of noise present because of incoherent light sources in non-coherent SAC-OCDMA. For non-coherent systems, the designed code consisted of modified- AND Subtraction detection method. This method divided spectrum of the particular code sequence to decrease the strength of the received signal. The technique is able to mitigate MAI and intensity effects with use of modified quadratic congruence code. In addition to it, usage of simulation experiment enhanced bit rate up to 1.25 Gb/s and system performance is achieved.

Tkach [119] introduced a hybrid OFDM Radio-over-Free-Space-Optics system for transmitting two independent channels by employing MDM technique. As Ro—FSO supports wireless networks, therefore 40GHz signals are modulated at 20Gbps using MDM consisting of LG00 and LG10 laser modes. The results revealed that LG00 performs better than LG01 mode in terms of signal constellation and received power irrespective of distance covered.

Tang [120] represented an article describing MDM based IsOWC system by using different types of modulation schemes such as MDRZ-DQPSK, DRZ-DQPSK and CSRZ-DQPSK. The set comprises of 64 LG modes for 64 channels for range varying from 900 to 4500km. Also, the system capacity is improved due to integration of LG modes and further MDM based system employ single laser usage. The simulation results revealed that MDRZ-DQPSK has best Q factor of 19.42 at 10Gbps as compared to other mentioned modulation formats. The CSRZ-DQPSK type has least Q factor because of large bandwidth requirement but it can be employed for large distance where cost is primary requirement.

Table 2.1: Progress in IsOWC system reported between 2013 and 2022

Author/Year	**Ref.**	**Design Parameters**	**Distance in km**	**Data Rate (in Gbps)**	**Purpose**
V. Sharma et al., 2013	25	10^{-6}, 850nm	1000	2.5	Low power requirement with and without the use of underroot module
S. Chaudhary et al. 2014	22	850 and 1545nm	1000	120	Analyzed WDM-PI scheme to design IsOWC by considering pointing errors of transmitter and receiver
A. Amphawan et al. 2015	19	1550.12nm	0.8	25	Demonstrated the benefit of keeping the channel space under control of a MDM based system with the help of HG modes to eliminate the BER and modal dispersion
A.O. Aldhaibani et al. 2015	121	1550nm	2500	2.5-10	Analyzed the performance by employing OFDM technology to increase the data rate of the channel, more users and power saving.
S. Chaudhary et al. 2016	73	1550nm	1000	120	Transmission of high data rate by adopting hybrid WDM and polarization interleaving scheme during pointing error

A. Alipour et al. 2017	20	0, 1600nm	1250	10,20,40	An ultra-high-capacity Is-OWC technology by employing various modulations schemes
S. Liao et al. 2017	21	800nm and 1550nm	53	20–400 Bps	Revealed the probability of satellite-based quantum communication for daylight transmission
R. Kaur et al.2017	18	750nm	2500	10,20,40	Detected the best modulation technique for 64 Channel IsOWC
S. Panda et al. 2020	122	10-20, 1550nm	40	2.5	Novel 2D wavelength/time code with ZCC property to minimize MAI in MDl prime hop code
T. Sharma et al. 2019	67	10-29, 1550nm	70	12	Usage of 1-D codes of eight types along with multiple array laser
H. K. Gill et al. 2019	107	10-25, 750nm	4500	10-40	64 LG modes are combined to improve the capacity of the system
A. Grover, 2020	123	1550nm	90	40	MDM-FSO based system have PSK technique combination to increase the system capability, also PoISK and the modulation schemes are compared
H. Sarangal, 2021	88	1550nm	12000	105	Analyzed hybrid inter satellite OWC non coherence system on the basis of PM zero cross correlation, further comparison of particular link is done with number of links
M. Singh et al. 2022	124	1550nm	10000	80	MDM based OFDM-IsOWC propagation is presented to record the impact of power at transmitter and the information related to angle of pointing error

2.3 Gaps in present study

This section entitles the most commonly faced drawbacks when dealing with Is-OWC systems and in addition to it MDM systems. This will help the reader comprehend the motive of these limitations and explain the reasons required to achieve the possible outcomes for these drawbacks.

1. The latest MDM based systems need advancement in existing fibers, optical amplifiers comprising of minimum components, MDM systems having in-built feature of MUX and DEMUX for attaining optimum output from the spatial region.

2. Limited development in the area of Is-OWC leads to prominent issues like problem of eavesdropping and insecurities while transferring of data.

3. In present technology novel code is designed but the issues like MAI and PIIN are minimized not eliminated due to tradeoff between bandwidth and frequency.

4. In future, IsOWC based MDM systems will be capable of providing more efficiency for spectral, maintaining minimum bandwidth requirement and low bit error rate with high Q factor.

2.4 Objectives

The objectives are given below:

1. To develop a novel OCDMA code with negligible cross-correlation for Optical Wireless Communication (OWC) System for improved bandwidth efficiency.
2. To design a high-capacity mode division multiplexing OWC system.
3. To investigate multilevel dual polarization-based modulation in OWC system for security enhancement.

2.5 Organization of Thesis

As per the objectives obtained in this research work, the thesis is categorized into six different chapters. The first chapter is devoted to introduce the reader to optical CDMA network and the security issues related to it. Also, the MDM based Is-OWC system incorporating different coding and polarization techniques are discussed. The inspiration and formulation of problem is depicted in this chapter. The main objectives of the thesis are also detailed. In addition to it, the complete thesis organization is represented. The main motivation to carry out this complete research is mentioned in **chapter 1**.

Chapter 2 mainly focus on the detailed literature survey of different techniques prevailing in the fieldof OCDMA which help to improve the security of the system and overcome the limitations. The workdone by different researchers and their analyzes will be addressed in chapter 2 itself. Further, the gapspresent in the latest study will be highlighted and objectives accomplished in the research will be explained in detail.

Chapter 3 discusses the first objective of the thesis in which a novel code named as ZCCRW SACbased OCDMA is proposed for a lower earth orbit based OWC system with 10Gbps of data rate for a range of 2500 km. In the developed ZCCRW code mapping is done freely and even there is flexibility to increase the user number with simple calculations. In addition to it, the proposed RD, MD, EDW and DDW code. The results revealed that the proposed ZCCRW code outperformed than the other codes in terms of Q factor, BER, extinction ratio and MAI due to sufficient bandwidth availability and absence of cross-correlation. The DDW code has more MAI and less signal to noise ratio because of fixed code weight and non-zero cross-correlation. In addition to it, there is absence of cross-correlation in MD code but limited bandwidth and less power tolerance leads to MAI. In case of proposed code, 16.5 Q-factor is achieved for 0.1 nanoseconds of chip size for a range of 4000km and BER of 10^{-9} is obtained by employing forward error correction scheme. **Chapter 4** covers the second objective that includes the proposal of a particular technique feasible forenhanced security version in optical CDMA systems. Firstly, the lower earth orbit is chosen for MDMbased OWC system by employing different types of spatial modes to attain maximum security level. The mathematical equations are used along with the simulation part to achieve least susceptibilityand security breaching in the newly proposed code. The ZCCRW code is compared with the already prevailing codes in terms of probability of eavesdropper, BER of reliable users, RMS jitterwhen users, line width of laser and range is varied. The analysis is done by inbuilding different modes such as LP, HG along with combination of different modulation schemes to observe the performance. The observations depicted that the MDRZ-DQPSK having LG mode outperformed than all the other combinations. Hence, to achieve maximum security with almost zero security breaching or in other terms least probability of estimation by the eavesdropper, the proposed codealong with hybrid modulation simulation is considered to be optimal.

Chapter 5 deals with last objective i.e., to validate the proposed Is-OWC technique. In this chapter performance investigation of multilevel dual polarization-based modulation is addressed in optical wireless communication system for security enhancement. The proposed system investigates different codes such as DDW code, MD code and ZCCRW code and compares their performance on the basis of distance and receiver pointing error angle. This system uses Optical CDMA scheme to enhance security level, data rates and minimize multiple access interference.

Finally, **chapter 6** comprises of the conclusions drawn; recommendations as per the results achieved in chapters 3 to 5 and scope for the future work is outlined.

CHAPTER 3

Investigation of ZCCRW-SAC codes in Inter satellite OWC system

3.1 Introduction

In this chapter, first objective is addressed to investigate the performance and design of the newly constructed code named as Zero Cross Correlation Resultant Weight using Low Earth Orbit. The main motive fulfilled in this chapter is to suppress multiple access interference with no mapping over optical wireless system in LEO. Thus, further comparison of different OCDMA codes such as MD and DDW code has been done with ZCCRW code and it is compared with respect to RMS jitter, multiple-access interference, quality-factor, Bit-Error Rate, extinction ratio, link lengths at various line widths, active users and chip sizes. This content has been presented as follows: - Section 2 represents the design algorithm of proposed ZCCRW code and the possible construction for different values of W and K, Section 3 comprises of the system set up and Section 4 deals with final Results and Discussions and Section 5 deals with conclusion.

3.2 Investigation of proposed ZCCRW code algorithm designed for zero cross correlation

It is known that there is urgently need to meet the demand for 5G services and RF communication system are not able to meet the future demands [125] and that is why it has been replaced by optical wireless communication systems which are more reliable, high data rate and huge bandwidth coverage [126]. To achieve optimum results, thorough knowledge of link design and channel is mandatory [127]. Nowadays, 100 Gbps data rate has been attained with optical wireless system. The most preferred technique in multiple access methods is OCDMA technique named as Optical Code Division Multiplexing Access Technique. The major benefit of OCDMA technique is that it allows multiple users to see mutually overlapped range of spectrum and it has certain advantages like improved security, flexibility in data rates and better QOS [128] with coverage of high bandwidth [43].

To implement this access technique, various methods of encoding are suggested [61,80-83] but overlapping of spectrum is the major issue. It would create MAI, co-channel interference and PIIN noise. So, in order to remove this PIIN noise and multiple access interference, construction of code carrying proper length and sequence is required [50]. There are various codes such as modified double weight (MDW) [129], modified frequency hopping (MHF) [54], FCC [130] and optical orthogonal code [131] which can overcome these limitations. As reported in [132], a novel ZCC code was designed which consisted of variable weight option and unlimited number of users. Also, Nisar [133] constructed a ZCC code which has the ability to withhold multiple users in addition to it, variable code length. Many studies have been done in the field of Is-OWC [18,21, 103, 134-136] but all these set ups have either of the drawbacks namely high price factor, low data rate or eavesdropping. It is observed that implementation of OWC system comprising of OCDMA is restricted owing to high-capacity requirement and effective coding. Hence, an efficient coding technique in which user number can be escalated to greater value without mapping is required in OWC. However as per the studies and literature present, there exists one of the most appropriate codes namely zero cross correlation (ZCC) comprising of simple system set up and low noise [84]. The most efficient method which overcomes the issue of over-lapping of spectrum is to design the desired efficient ZCC code which contains the weight that can be changed and has no limitations to no. of users [137]. In this chapter, major investigation is done on proposed ZCCRW code without mapping and the benefit to design is that it is for any number of users.

SAC-OCDMA codes are quite efficient as it has low-cost operation in OWC systems as LEDS known as light-emitting diodes were used in the systems using FBGs. But due to its wide spectrum, directionality which is random, there is limitation in the use of LEDs. In this chapter, ZCCRW code is constructed without the mapping technique and there are used of code lengths controlled for the provision of less multiple access interference, easy construction and high efficiency of bandwidth.

3.2.1 Construction of ZCCRW code comprising of different values of W and K

The proposed ZCCRW code is characterized by using various parameters like K, W and λ_c. Here, K symbolizes no. of users, weight is represented by W and λ_c is represented by code cross-correlation. The proposed ZCCRW code has flexibility in its nature as there is variation in weight as per the needs. ZCCRW code has similarity with existed SAC codes that it uses direct detection therefore there is no requirement to use the extra filters and therefore it leads to less cost needs. ZCCRW code is based upon the restraining condition of resultant weight which is for the base matrix and it is written as

$$W_R = W-1 \quad (3.1)$$

Otherwise, length of code is long due to complicated calculations. After the analysis of simulation, evaluation has been considered in the various sections described as follows. In order to calculate the code length of the proposed, the relationship between the employed users denoted by K and resultant weight denoted by W_R needs to be formed.

$$L = (K * W_R) + K \quad (3.2)$$

Therefore, consider I_B be the balanced matrix size which is written as:-

$$I_B = 2 * W_R \text{ (Balanced)} \quad (3.3)$$

There is construction of simple K*L matrix in which there is no limitation put on number of users and flexibility is there in selecting users.

$$I_B = \begin{bmatrix} R_1 \\ R_2 \end{bmatrix} = \begin{bmatrix} (W/2)\ 1's & (W-2)0's \\ \{(W+2)/3\}\ 0's & \{(W+1)/2\}\ 1's \end{bmatrix}_{2xW_R} \quad (3.4)$$

Here, Row 1 and Row 2 are represented by R_1 and R_2 and these are present in I_B matrix and weight of code is represented by W= 1,2…, W_R. Matrix M will represent complete set of size K*L for K number of users. M consists of different steps, first of all there is construction of M_1 intermediary matrix, thus I_B matrix has been repeated N-1 times and this is described by the following equation: -

$$M_1 = \begin{bmatrix} R_1 & \dots & \dots & \dots & R_2 \\ R_2 & R_1 & \dots & \dots & \dots \\ \dots & R_2 & R_1 & \dots & \dots \\ \dots & \dots & R_2 & R_1 & \dots \\ \dots & \dots & \dots & R_2 & R_1 \end{bmatrix} \quad (3.5)$$

This process will need to get repeated K*L times and it is shown in M_2 matrix.

$$M_2 = \begin{bmatrix} R_1 & \dots & \dots & \dots & R_2 \\ R_2 & R_1 & \dots & \dots & \dots \\ \dots & R_2 & R_1 & \dots & \dots \\ \dots & \dots & R_2 & R_1 & \dots \\ \dots & \dots & \dots & R_2 & R_1 \end{bmatrix}_{KxL} \quad (3.6)$$

As shown in the matrix M_2, zeroes have been filled where there are empty spaces and M_3 matrix has been represented as given: -

$$M_3 = \begin{bmatrix} R_1 & 0 & 0 & 0 & R_2 \\ R_2 & R_1 & 0 & 0 & 0 \\ 0 & R_2 & R_1 & 0 & 0 \\ 0 & 0 & R_2 & R_1 & 0 \\ 0 & 0 & 0 & R_2 & R_1 \end{bmatrix}_{KxL} \quad (3.7)$$

Therefore, right shifting operation is done as per the weight ‘W’ presented in the row given by the formula represented as: -[Weight*Row number-Weight-Row no. +1]. Also, matrix has been added as $\{(R-1)0's+W-(W_R)1's\}$ K*K to the shifted row matrix.

Construction of M will be done after addition operation comprising of L= (K*W_R) +K. Fig. 3.1 is used to describe the flow diagram of ZCCRW code.

According to the ZCCRW properties, mathematically expression has been given related to SNR as described in [67]: -

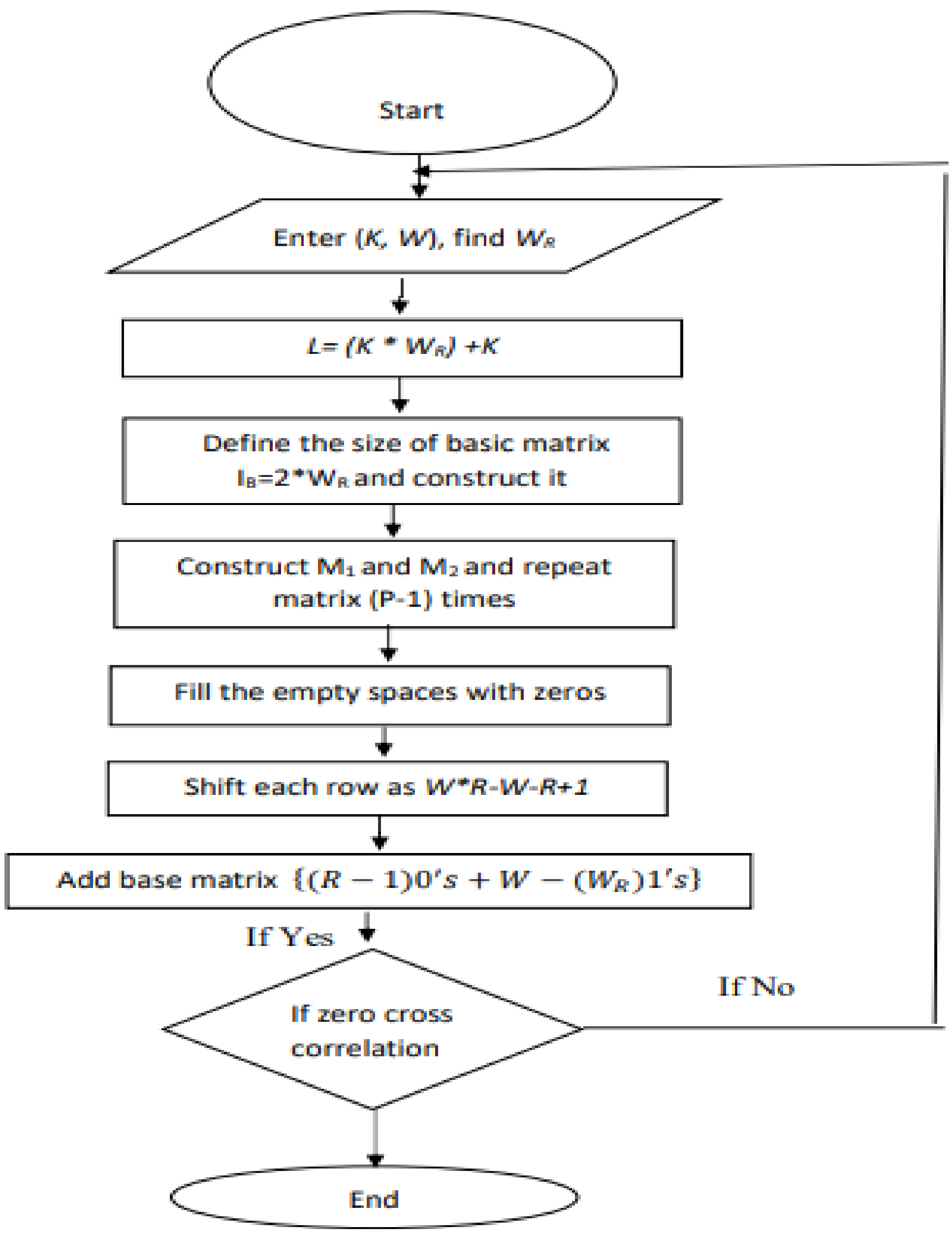


Fig. 3.1 Flow diagram of ZCCRW code

$$\text{SNR}=\frac{\left(\frac{RWP_{Sr}}{N}\right)^2}{\frac{2eBRP_{Sr}(W+3)}{N}+\frac{BP_{Sr}^2KW(W+3)R^2}{\Delta v N^2}+\frac{4K_bT_nB}{R_L}} \qquad (3.8)$$

Here photodetector responsivity is denoted by R, code weight is represented by W, output effective power source is represented by P_{sr} and code length is represented by N.
For the evaluation of performance of system, the most important parameters include Q- factor and BER as given in [111].

$$Q=\frac{|\mu_1-\mu_0|}{\sigma_1+\sigma_0} \qquad (3.9)$$

Here Q-factor describes quality of input signal that is calculated numerically by employing standard deviation (σ_1, σ_0) as well as the mean values (μ_0, μ_1) as given in the paper.
Therefore, P_e termed as probability of error which transmits through optical wireless channel can be determined by the formula given in [138]: -

$$P_e = \text{BER}= \frac{1}{2}\text{erfc}\left(\frac{Q}{\sqrt{2}}\right) \qquad (3.10)$$

Erfc is used to describe the complimentary function of error. Therefore, with the use of average values as well as the standard deviations taken in the values sampled, the extinction ratio is given by the equation in [56]: -

$$E_R = \frac{\mu_1}{\mu_0} \qquad (3.11)$$

3.3 System set up and simulation

This set up of ZCCRW code using 1D has been simulated using Optisystem version 16. This circuit comprises of seven users having code weight around 3. At the input signal, CW lasers named as Continuous wave lasers have been used as depicted in Fig. 3.2. Power at laser is taken at 0 dBm and total 21lasers are used to accommodate equal to bit rate of system. Width of spectral for every chip is 0.8 nm having frequency of 100 GHz.
First of all, pseudo random bit sequence generators (PRSB) have been used to provide the coded data which has been encoded and it is further sent to NRZ generator (Non-Return to Zero). MZM Modulator named as Mach-Zehnder Modulator has been used for data modulation. Rate of data

bit is considered to be 10 Gbps and wavelength division multiplexing has been used to multiplex the signal and further amplification is done by amplifier of 20 db. Then transmitter is sent to optical wireless channel and it provides spectrum band and this channel is used to provide the communication between transmitter and receiver.

At the receiver part, de-multiplexing has been done to 7 different receivers. Antenna diameter is taken around 15 cm for both transmitter and receiver. Attenuation is considered approximately 0.14 db/km as if it is taken upto 100 km, then there will be some weather conditions and fluctuations affecting above earth. Bessel optical filter has been used at the receiver part to obtain the designed data which is needed at the receiver end. These filters are employed to choose the specific wavelength required for coding of every user. Optical signal converts to electrical signal with a photodetector of 1nano ampere current and responsivity around 1A/w. The output is taken at BER analyzer named as bit error rate analyzer which is employed to check the desired signal. The various parameters employed for simulating the code and numerically calculating the values are given in Table 3.1.

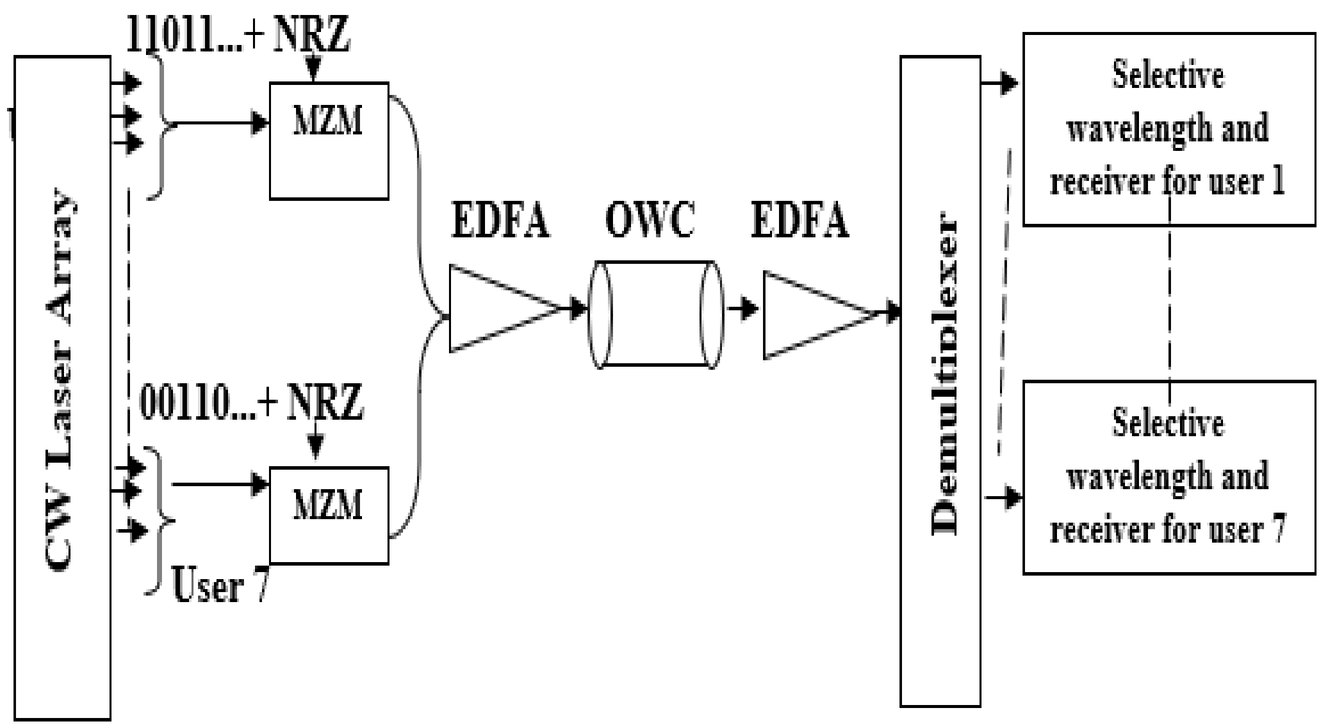


Fig. 3.2 Optical wireless system (proposed) using ZCCRW code

3.4 Results and Discussions

Comparison is made between the existed codes to check and measure the efficiency of ZCCRW code. The various parameters have been taken into account that is discussed above. ZCCRW code has proven out to be best code design having (W, N, λ_c) parameters to provide lowest bit error rate, minimum Multiple-access interference and achieving high quality factor. To check and validate the efficiency of the proposed system, bit error rate values has been calculated at different distances.

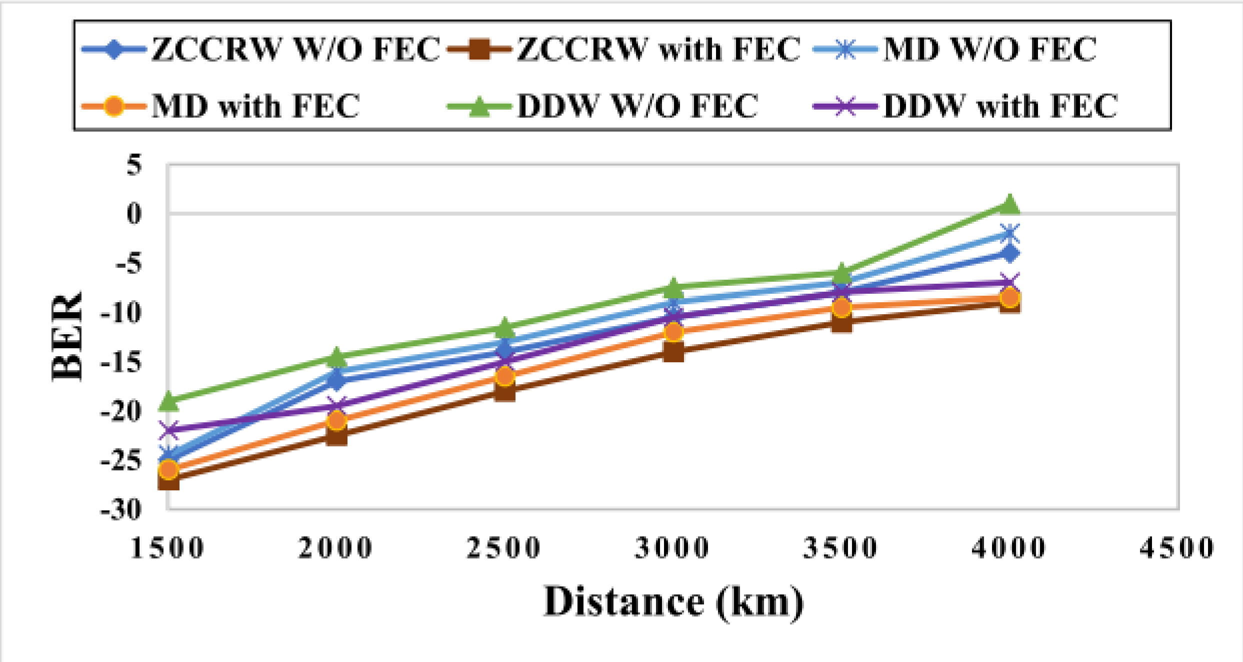


Fig. 3.3 Variation of BER with different distances with and without FEC for different codes

The variation of bit error rate with the different distances for different codes has been shown in Fig. 3.3 and it is shown with and without forward error correction and codes being compared with existing codes. From the graph, it is clearly observed that MD code (multi-diagonal code) and DDW code (double diagonal weight code) shows less system performance in comparison with proposed ZCCRW code at the distance of 4000 km. The proposed ZCCRW code shows better performance with bit error rate of 10^{-4} without FEC and 10^{-9} with FEC. This has been also observed that with the increase in distance, bit error rate will also increase because distortion of signal will increase directly with the distance, so there will be increase in bit-error rate. The obtained values with FEC are better than without FEC.

Table 3.1: Simulation parameters employed in the proposed set-up.

Simulation parameters	**Value**
Channel	OWC
Total distance covered	2500 km
Distance of every loop	250 km
Transmitter's and receiver's aperture antenna	15 cm
Attenuation	0.14 db/km
Optical amplifier	EDFA
Wavelength band used	C band

So, the effect of laser linewidth is also done with respect to output extinction ratio of various SAC codes as shown in Fig. 3.4. Linewidth means variation in the spectrum around the carrier. It has been analyzed that because of cross correlation presence in multi-diagonal codes and DDW codes where 15.3 and 13.7 are the values, proposed code possesses better value of extinction ratio that is around 47.9.

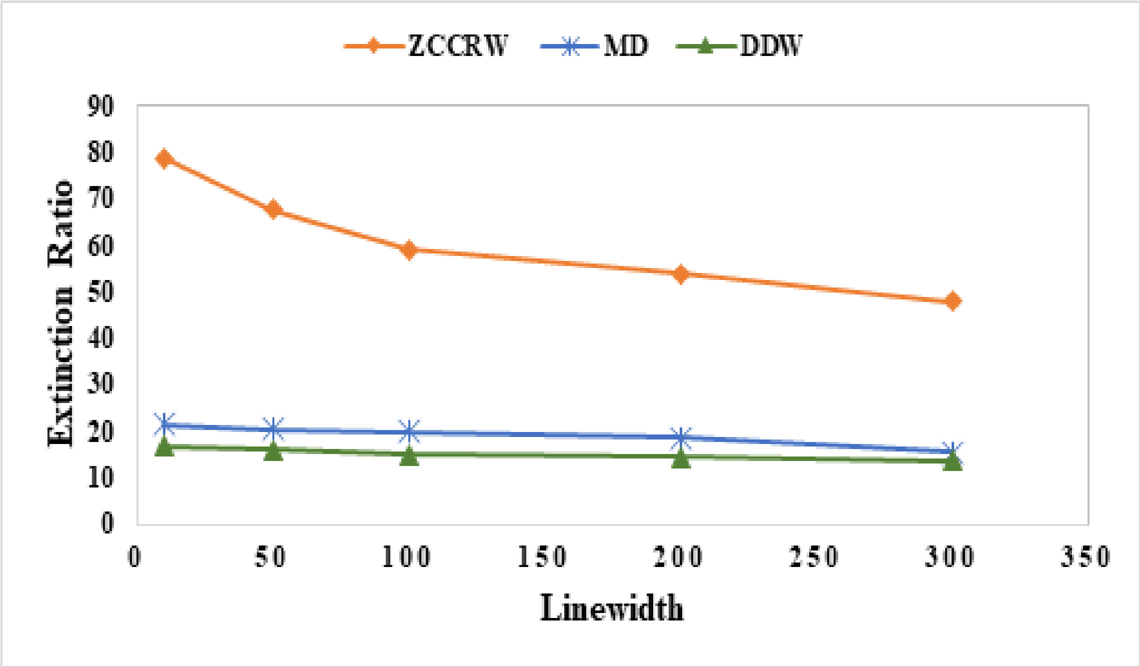


Fig. 3.4 Graph of laser linewidth versus extinction ratio for various SAC codes

From the graph, it is also observed that higher the ER value, less will be the input value of power that is needed for operation. Fig. 3.5 reflects a comparison analysis of ZCCRW code with the prevailing codes for various values of extinction ratio and it is compared on the basis of RMS jitter. Extinction ration values have been varied from 5 upto 45 to check optimal point. It has been observed that at the value of weight W= 3 in proposed code of ZCCRW, RMS jitter will decrease on increasing the extinction ratio. DDW code shows higher values of jitter due to correlation having fixed weight W=2. It is also evaluated that when weight is less, signal to noise ratio will also decrease and jitter value will also increase.

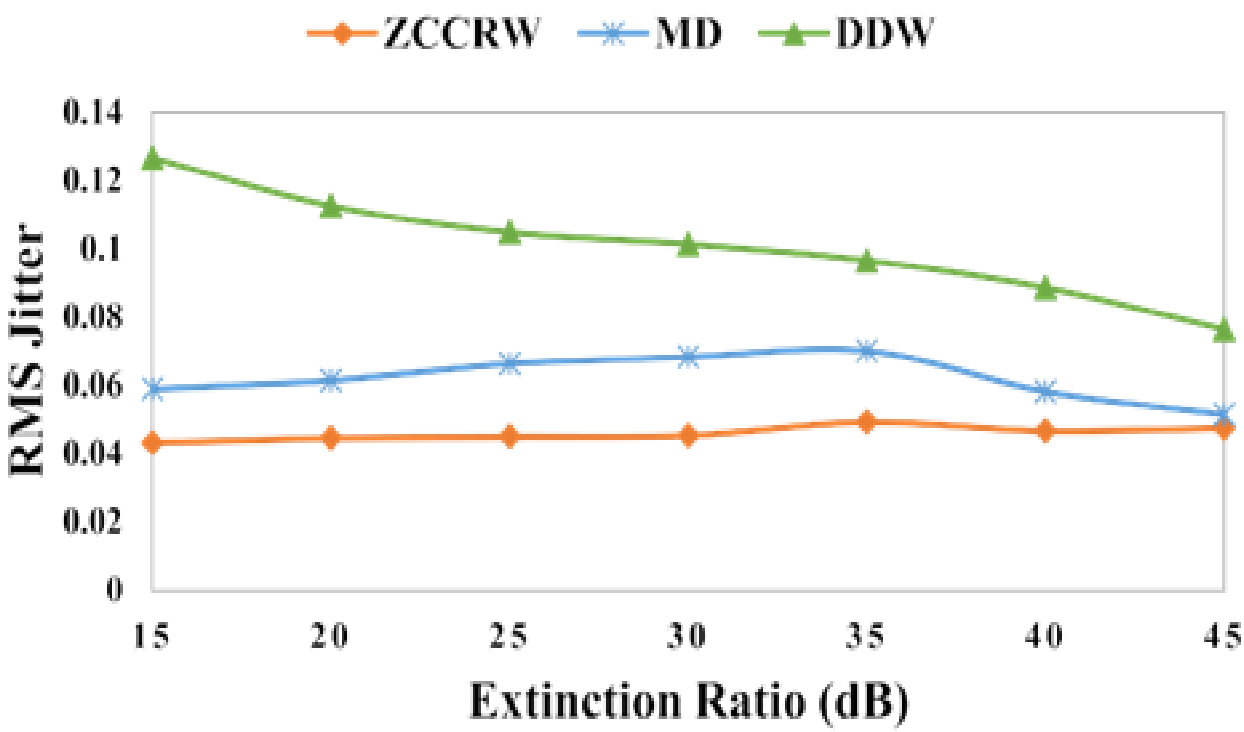


Fig.3.5 Comparisons of different SAC codes in accordance to root mean square jitter versus ER

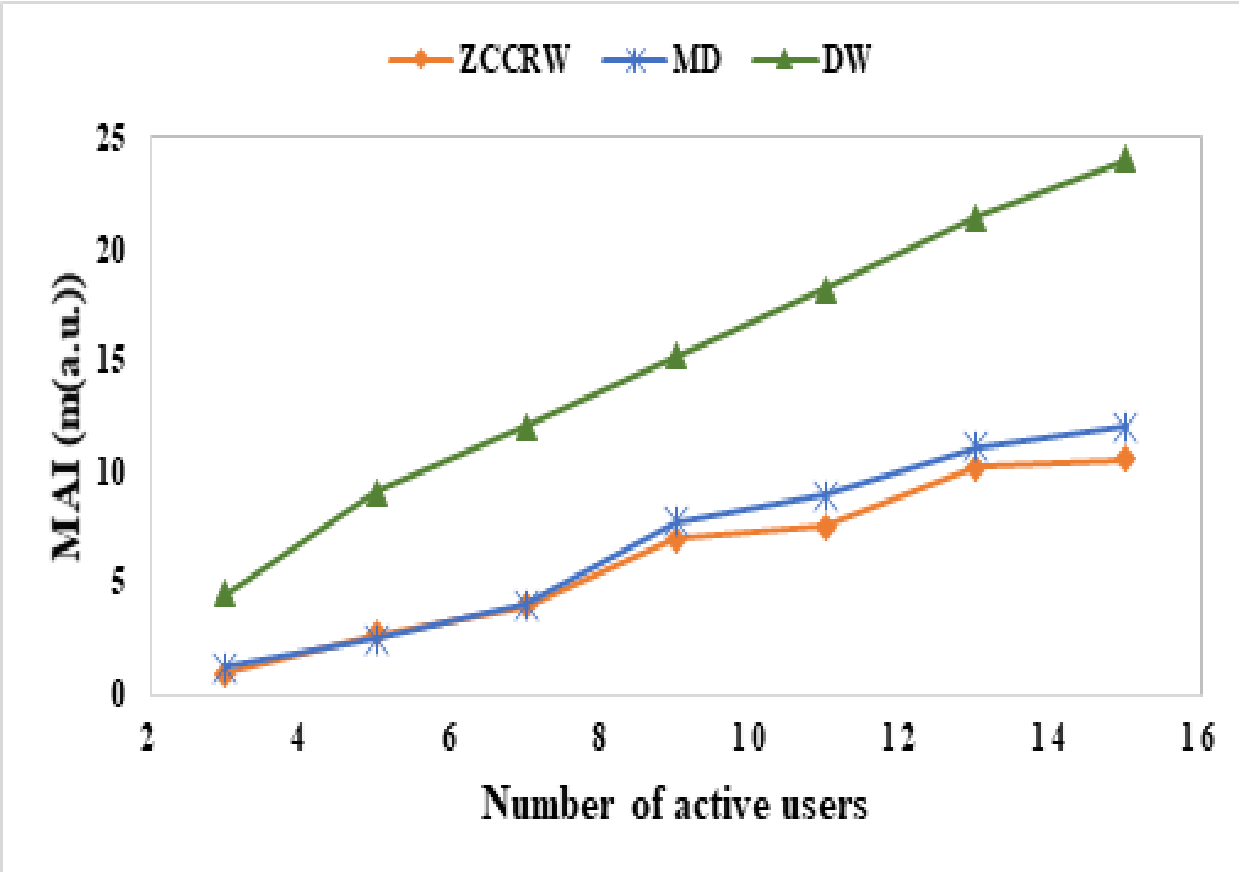


Fig. 3.6 Graph of changes in MAI when no. of users for different codes are varied

Fig.3.6 describes changes in MAI when no. of users for different codes are varied for proposed code i.e., ZCCRW, existing ones- MD and DDW code respectively. Here input source power is taken at 0dBm. DDW codes shows maximum multiple access interference as it shows cross correlation of 1. Generally, ZCC codes does not show multiple access interference but because of non- linearity effects and combined power, multiple access interference exists within the channel. ZCCRW codes show least MAI in comparison with MD codes.

As time slot decreases, there is increase in data rate but errors will get increased for all OCDMA based codes. From the results obtained with various simulations, it is clearly observed that highest quality factor is obtained in the case of ZCCRW code that is 16.5 for minimum chip size around 0.1 ns and quality factor around 9.8 for chip size around 0.2 ns and it is given in Fig.3.7. Size of chip increases on moving from left side to right side on horizontal axis that would mean that there is decrease in data rate following same trend. High quality factor can be observed with higher size of time slot like 0.1 nanoseconds. The systems set up comprises of lasers in proposed ZCCRW code based on SAC for better SNR and high efficiency.

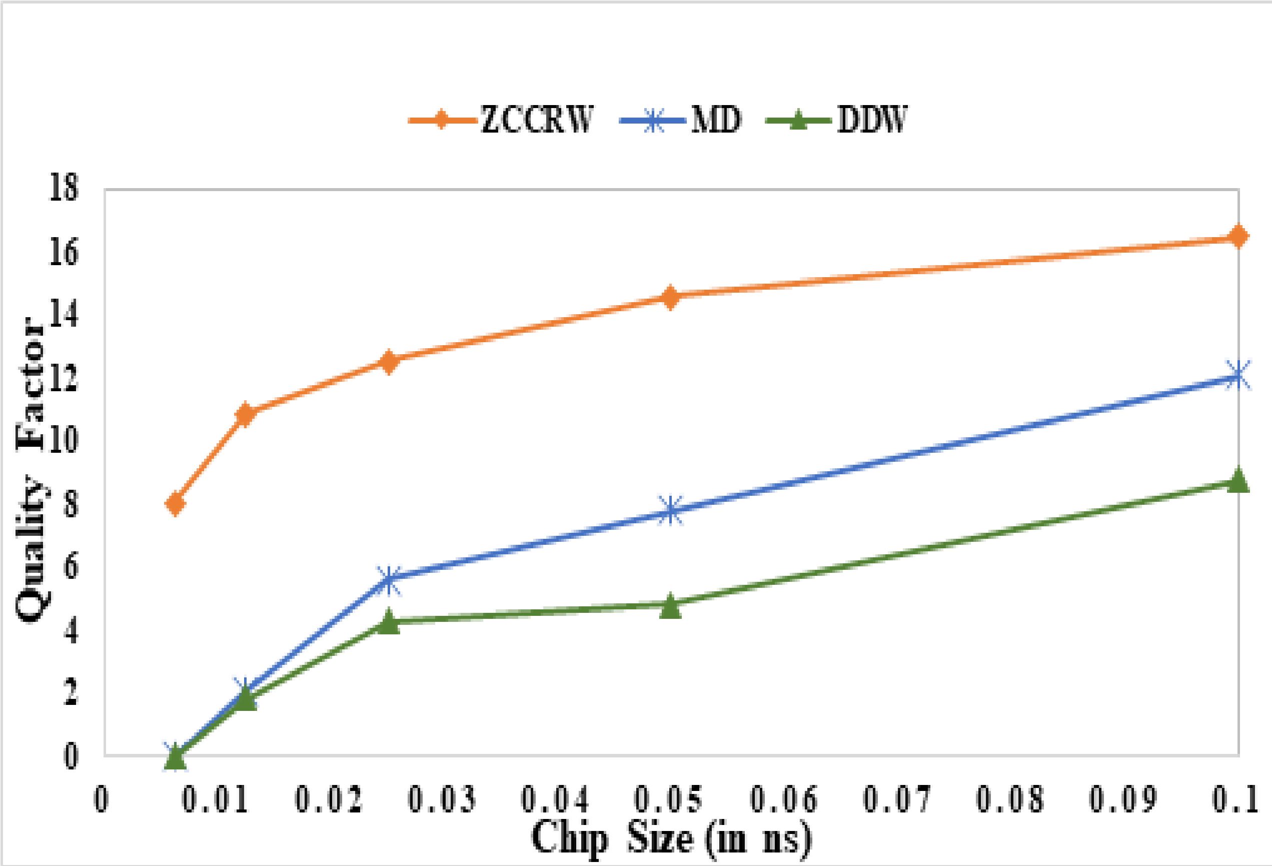


Fig.3.7 Graph of Quality factor v/s chip size for ZCCRW, MD and DDW codes

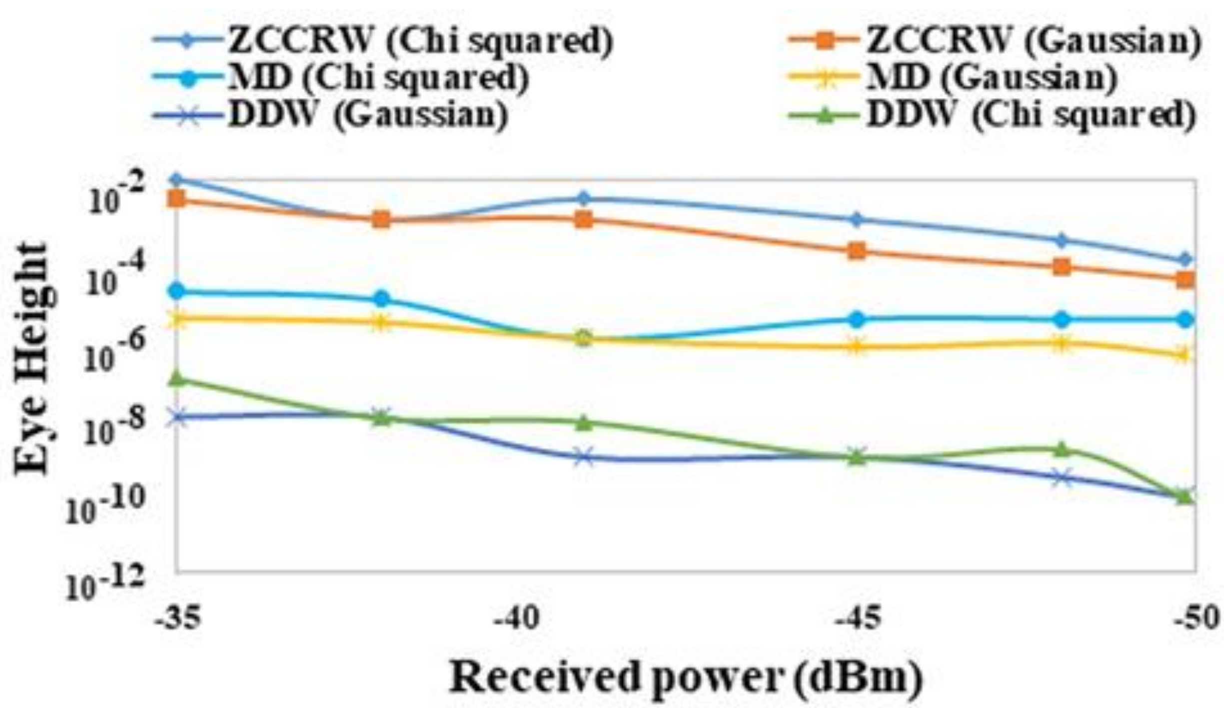


Fig.3.8 Graph of eye height of OCDMA Codes versus received power

Fig.3.8 is used to describe eye height of various OCDMA codes versus power received when there is usage of two different algorithms that is Gaussian Algorithm and Chi-squared Algorithm. The calculated results have been obtained from expression 3.12 likewise in [138].

$$E_H = (\mu_1 - 3\sigma_1) - (\mu_0 + 3\sigma_0) \qquad (3.12)$$

Here σ_0 as well as σ_1 are the standard values taken for sample0as well as1. In the same way, $\mu_0$as well as$\mu_1$are the meanvaluesofsample0as well as1.

Gaussian algorithms have been used for bit error rate calculation.

$$P_e = \frac{M}{N+M} P_{eo} + \frac{N}{N+M} P_{e1} \qquad (3.13)$$

In above equation, P_{eo} , P_{e1} represent the probability of respective symbols (1's and 0's) and M represents number of samples for the logic 0, and N represents number of samples for the logic 1.

$$P_{e0} = \frac{1}{2}\, erfc\left(\frac{S-\mu_0}{\sqrt{2}\sigma_0}\right) \qquad (3.14)$$

$$P_{e1} = \frac{1}{2}\, erfc\left(\frac{\mu_1-S}{\sqrt{2}\sigma_1}\right) \qquad (3.15)$$

In equation 3.14 and 3.15, S denotes threshold value.

In Chi squared algorithm, BER is specified as:

$$P_{e1} = \frac{1}{2N} \sum_{i=1}^{N} erfc\left(\frac{\mu_{1i}-S}{\sqrt{2}\sigma_{1i}}\right) \qquad (3.16)$$

$$P_{e0} = \frac{1}{2M} \sum_{i=1}^{M} erfc\left(\frac{S-\mu_{0i}}{\sqrt{2}\sigma_{0i}}\right) \qquad (3.17)$$

The above equation is altered when mixed noise is present and below mentioned result is obtained.

$$P_e = \sum_{i=1}^{S} \frac{N_p}{N}\, erfc\left(\frac{\mu_i-S}{\sqrt{2}\sigma_i}\right) \qquad (3.18)$$

The overall patterns and only 1’s are N and N, individually. Here sample’s average value is taken to be μ_i and standard value of sample is σ_0, S is the threshold value, further, P_e for this case is defined in 3.19.

$$P_e = \frac{M}{N+M} \int_{S}^{\infty} f_{\aleph^2}\left({}^{x}/_{0}\right) + \frac{N}{N+M} \int_{-\infty}^{S} f_{\aleph^2}\left({}^{x}/_{1}\right) \qquad (3.19)$$

From the results, it is quite clear that chi-squared algorithm that is based upon the proposed ZCCRW code provides better results due to code length which is controlled and zero cross correlation. DDW codes provides least results in case of Gaussian algorithm case because of less weight code which is fixed and non-zero cross correlation i.e., around 1 and 2. To get low signal to noise ratio, weight of the code should be less. It is also suggested to prefer chi-squared algorithm in the proposed system based upon ZCCRW codes to obtain better eye height.

Table 3.2: Comparison between various codes on the basis of its characteristics used for SAC based OCDMA

SI.no.	**Different Codes**	**User number (K)**	**Weight(W)**	**Length of code (L)**	**Cross-correlation (λ_c)**
i.	RD	7	4	12	Variable
ii.	DDW	7	2	8	1
iii.	EDW	7	3	14	1
iv.	MDW	7	4	21	1
v.	ZCC	7	4	14	0
vi.	ZCCRW	7	2	14	0

Table 3.2 is used to describe the comparison between existed codes and the proposed ZCCRW code in the terms users employed, code length and cross-correlation. Validation of work is done in Fig.3.9 to obtain the effect of no. of users w.r.t signal to noise ratio in the proposed system. The parameters which are used to receive results include wavelength around 1550 nm having code length of 14 at the distance of 2500 km and weight 2. Results shows that the proposed ZCCRW code provides good performance than DDW and MD code.

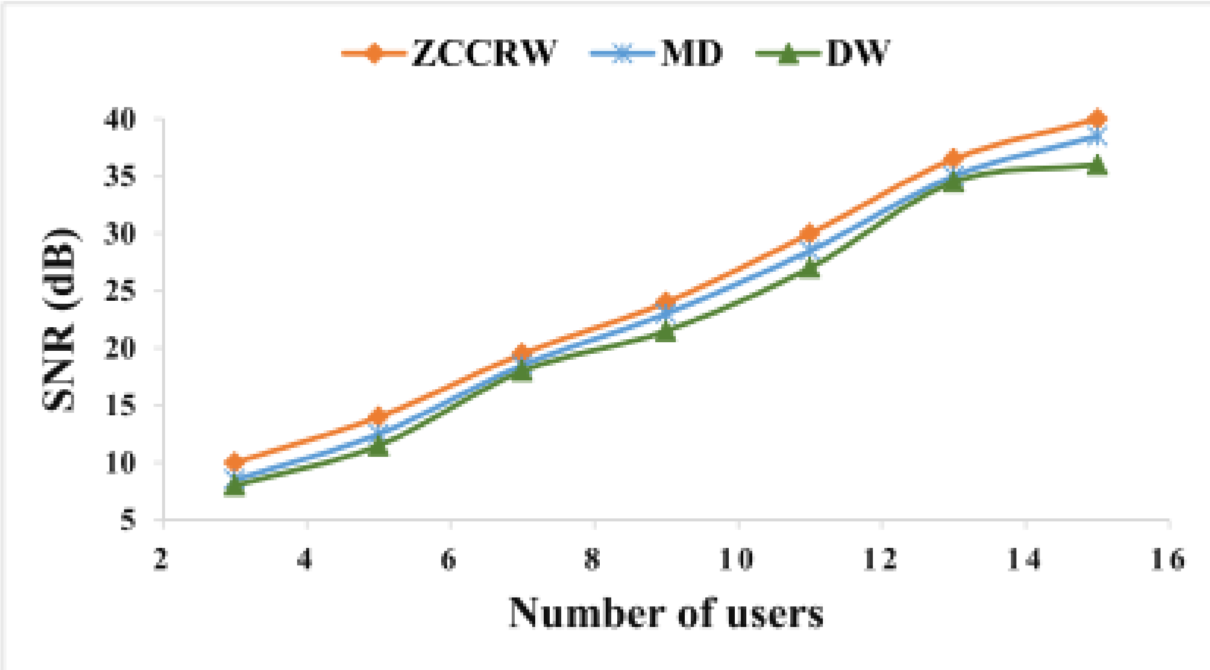


Fig.3.9 Graph of signal to noise ratio v/s total users employed for proposed ZCCRW, MD and DDW code

3.5 Conclusion

In this chapter, zero cross correlation SAC based OCDMA code has been proposed for optical wireless system for lower earth orbits operating at 10 Gbps rate and distance is taken at 2500 km. The suggested code is free from mapping and increasing the users is possible without any large calculations. Also, ZCCRW, MD and DDW codes have been compared. Results reveal that ZCCRW code has proved to be best in terms of Q-factor, extinction ratio, minimum BER and MAI in comparison with DDW and MD code. ZCCRW code contains highest efficiency of bandwidth and cross correlation is zero. DDW code have fixed weight that is 2, has high multiple access interference, cross correlation around 1 and less signal to noise ratio. Also, MD codes contain ZCC but it contains less tolerance of power and less efficiency. It has also been analyzed that Quality factor for the proposed ZCCRW code is 16.5 with the chip size of 0.1 ns, BER is 10^{-47} at the distance of 2500 km using forward error correction technique.

CHAPTER 4
PERFORMANCE OF MDM OWC USING HYBRID MODULATION

4.1 Introduction

This chapter addresses the design of ZCCRW code with improved modal and simulation parameters, which represents the fulfillment of the second objective of thesis work. To achieve this, a novel ZCCRW code has been implemented in LEO-based MDM-OWC system. This chapter also includes the technique opted to enhance the security of the OCDMA system. Three codes have been compared and investigated using simulation software and derivation of mathematical expressions under eavesdropping effects. Combination of Hermite-Gaussian modes (HG) and Laguerre-Gaussian modes (LG) is compared with hybrid modulation to check the optimal modulation. The content has been presented in various sections described as follows: - Section 1 describes principle of security enhancement and design of OCDMA code. Section 2 describes system set up which illustrates the model of coherent OCDMA where incorporation of existing SAC codes is performed and Section 3 describes results and outcomes have been discussed.

4.2 Designing of OCDMA code

In the present times, there is demand of high-speed data rate and to meet this requirement, some innovative strategies need to be opted in OWC system [123]. It is known that OWC systems have gained much importance in comparison with RF communication system. The major benefits of optical wireless communication system include huge bandwidth, high speed, high security and immunity towards electromagnetic interference [107]. These days, for OWC, effective coding methods based on OCDMA are given more importance than the existing TDM and WDM techniques for different network areas [114, 139]. OCDMA is the most efficient coding method as it allows scalability and flexibility for higher traffic in the allotted channel.

Unfortunately, these reported codes suffer from few drawbacks namely complex code design [140], long code length [43], variable cross correlation [54], lack of security against jammer and eavesdropper [107], high cost [115-116] and MAI [43]. In Optical based CDMA systems, MAI, variable cross-correlation and larger length of code is the major issue which limits data rate and affects the performance. To eliminate the issue of leakage of confidential information, various studies have been done by using hybrid codes [64], optical logic operation [65], data scrambling [141], multi code keying [95], 2-D modulation format [26], temporal phase coding and code shift keying [49] and two- dimensional/ three-dimensional codes [68]. Hence, to obtain all these positive aspects, various codes with various tradeoffs have been developed [26,61]. Above all cost is the major concern which needs to be adjusted, therefore during previous years' work has been done to propose a system comprising of either fixed or low weight (like in DDW W=2) [69], MDM based random diagonal codes [64]. The above-mentioned codes either provide low SNR or less data rate owing to low weights. The main concern of OWC system is to send the data without any sort of leakage of sensitive information [61,66]. It has been reported that security leaking is found at various levels in Is-OWC set ups such as at transmitter station, channel or inside the satellite [70]. After a thorough evaluation, it is noted that highest security breaching takes place in the channel which can be controlled by designing an efficient transmitter [71]. To combat the desired need, MDM technique is showing a remarkable response by using only one laser with LP modes comprising of intensity profiles too [104, 107] and further leading to cost efficient set up [64,72-74, 111]. On the other hand, TDM has issue of time skew and WDM uses n number of lasers leading to high price [57]. MDM can withstand different techniques such as integrated modulation, hybrid modulation [64,74], DPSK, DQPSK and Manchester modulation [107] and polarization division multiplexing. The major positive aspect of hybrid technique is that it supports multiple modulation or additional phase shifts to attain desirable results. Hence, the presently available OWC systems provide free mapping, enhanced security with low cost and support multiple users with optimum code length and variable code weight.

Huge cost and less security against eavesdropping are constraints affecting performance of OCDMA system. So, in order to solve the issue, ZCC codes have come as an alternative solution to the problem. One dimensional ZCC is constructed with 3 parameters named as K, λ_c and W. Here K describes the supported users, λ_c represents cross correlation value present in code and W expresses weight of code. Relationship between the weight and the supported users has been made and resultant weight will be equal to $W_R = W-1$. It is used to calculate the required code.

$$L = (K * W_R) + K \tag{4.1}$$

I_B denotes the size of matrix and it is described as: -

$$I_B = 2 * W_R \tag{4.2}$$

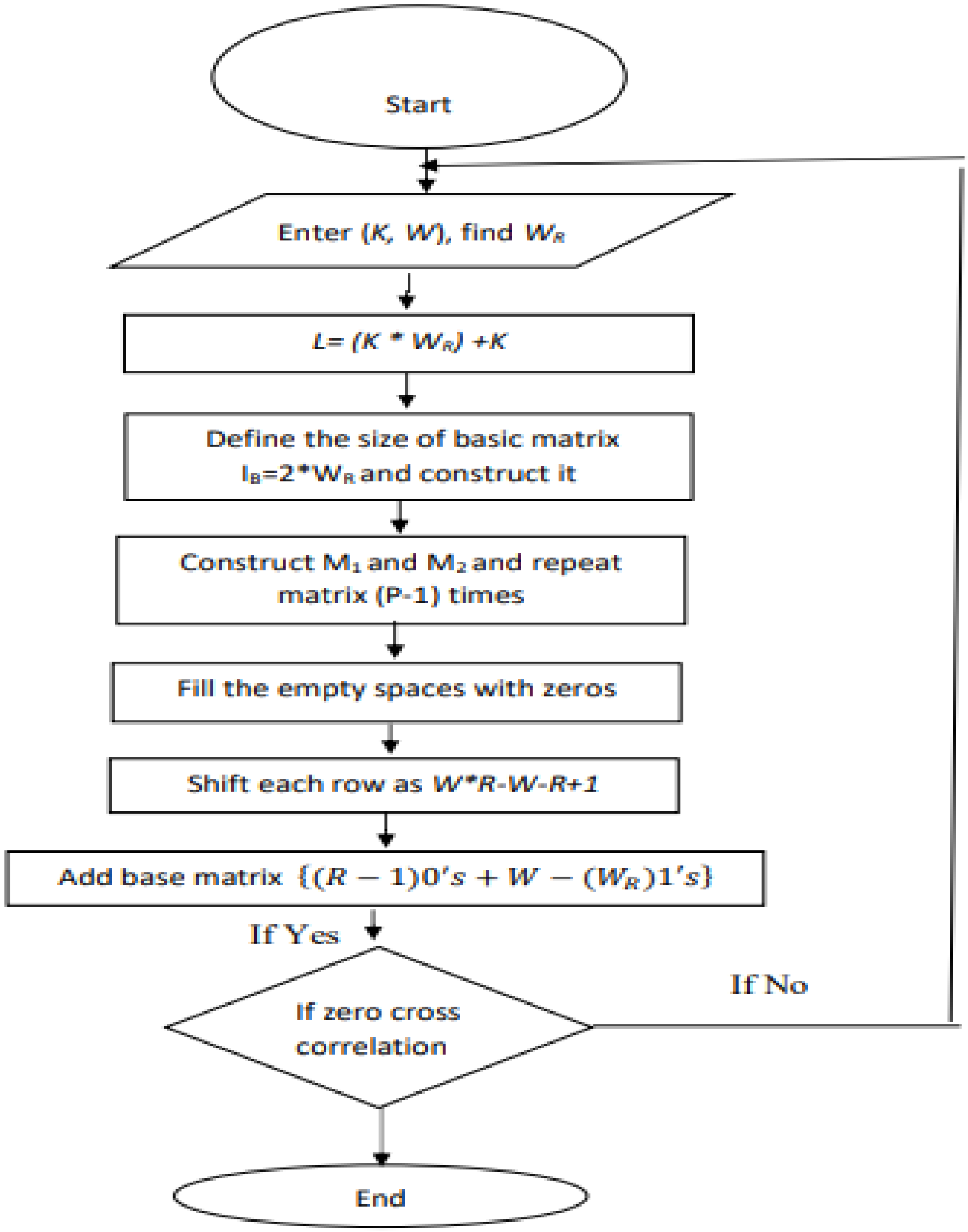


Fig.4.1 Flow diagram of ZCCRW code

It is balanced and it is constructed without limiting the number of users.

$$I_B = \begin{bmatrix} R_1 \\ R_2 \end{bmatrix} = \begin{bmatrix} (W/2)\ 1s & (W-2)0s \\ \{(W+2)/3\}\ 0s & \{(W+1)/2\}\ 1s \end{bmatrix} \quad (4.3)$$

R_1 and R_2 describes Row 1 and Row 2 of I_B, matrix M represents the complete matrix having size K*L for K = no. of supported users. M_1 matrix has been firstly constructed which includes various steps for the full composition of matrix M. I_B has been repeated N-1 times which is described as follows: -

$$M_1 = \begin{bmatrix} R_1 & \dots & \dots & \dots & \mathrm{R}_2 \\ R_2 & R_1 & \dots & \dots & \dots \\ \dots & R_2 & R_1 & \dots & \dots \\ \dots & \dots & R_2 & R_1 & \dots \\ \dots & \dots & \dots & R_2 & R_1 \end{bmatrix} \quad (4.4)$$

To present the matrix of M_2, the repetition of process is required K*L times.

$$M_2 = \begin{bmatrix} R_1 & \dots & \dots & \dots & \mathrm{R}_2 \\ R_2 & R_1 & \dots & \dots & \dots \\ \dots & R_2 & R_1 & \dots & \dots \\ \dots & \dots & R_2 & R_1 & \dots \\ \dots & \dots & \dots & R_2 & R_1 \end{bmatrix}_{KxL} \quad (4.5)$$

In describing every code row of M_2 matrix, zeroes have been filled where there are empty spaces and therefore formation of M_3 matrix is given as below: -

$$M_2 = \begin{bmatrix} \mathrm{R}_1 & 0 & 0 & 0 & \mathrm{R}_2 \\ \mathrm{R}_2 & \mathrm{R}_1 & 0 & 0 & 0 \\ 0 & \mathrm{R}_2 & \mathrm{R}_1 & 0 & 0 \\ 0 & 0 & \mathrm{R}_2 & \mathrm{R}_1 & 0 \\ 0 & 0 & 0 & \mathrm{R}_2 & \mathrm{R}_1 \end{bmatrix}_{\mathrm{KxL}} \quad (4.6)$$

Weights has been taken as W=0,1,2… R and right shifting operation is done as per the weight of the code i.e., W presented in the row given by the formula represented as: -

[Weight*Row number-Weight-Row no. +1]. Also, matrix has been added as$\{(R-1)0's + W - (W_R)1's\}$ K*K to the shifted row matrix.

Construction of M will be done after addition operation comprising of L= (K*W_R) +K.

According to the ZCCRW properties, mathematically expression has been given related to SNR and it is discussed in [67].

$$\mathrm{SNR}=\frac{\left(\frac{RWP_{sT}}{N}\right)^2}{\frac{eBRP_{sT}(W.W)}{N}+\frac{4K_bT_nB}{R_L}} \quad (4.7)$$

Here responsivity of photodetector is represented with R and code weight is represented with W and effective source of power at output is denoted by P_{sr}. Code length is denoted by N.

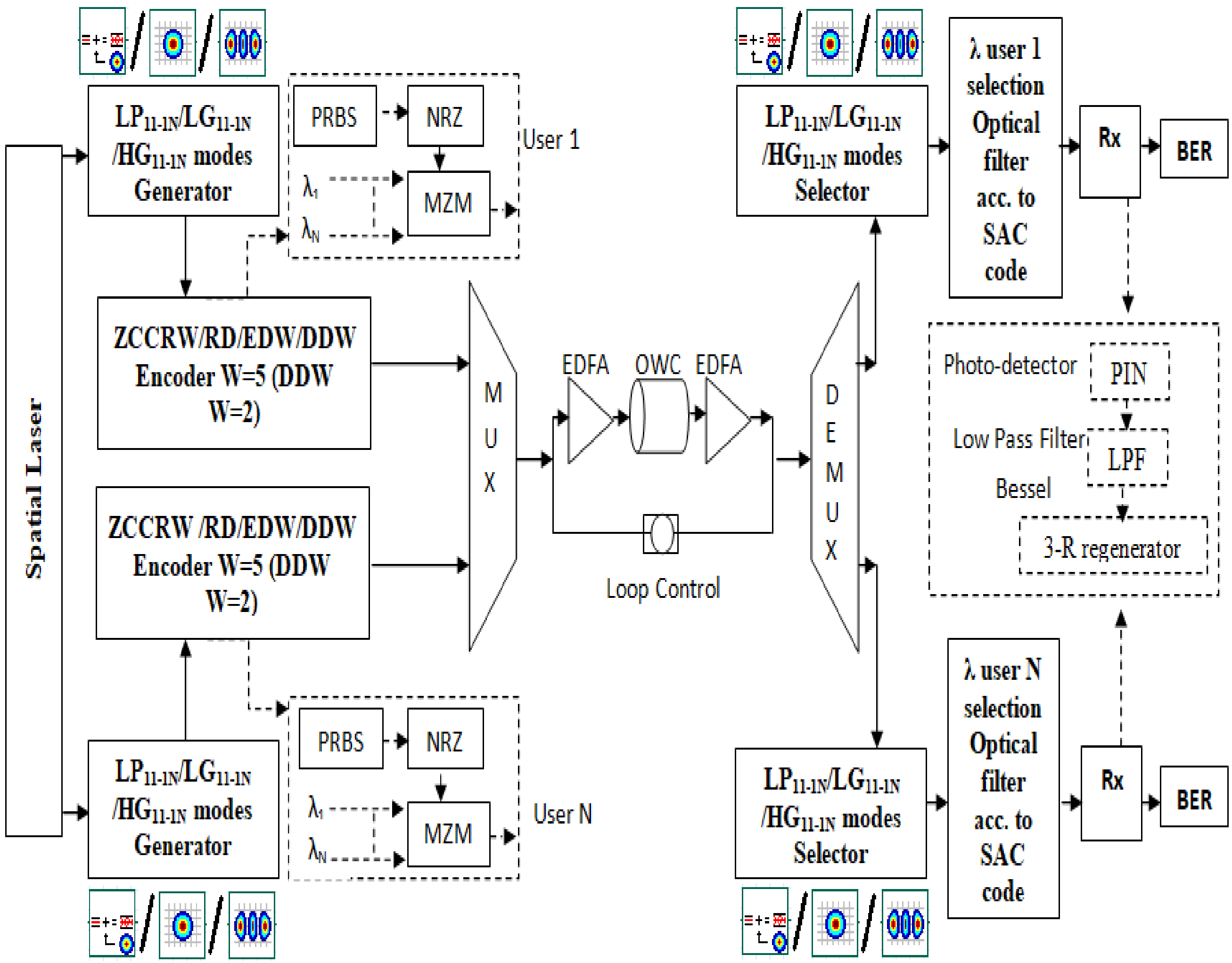


Fig.4.2 Proposed MDM based ISOWC set-up by employing various SAC codes

Fig. 4.2 shows the proposed MDM based ISOWC set-up by employing various SAC codes. To evaluate the performance of the system, the considerable parameters required are Q factor and BER.

$$Q= \frac{|\mu_1-\mu_0|}{\sigma_1+\sigma_0} \qquad (4.8)$$

Q-factor describes input signal quality that is calculated numerically by employing the standard deviation and mean values as mentioned in the paper. Therefore, P_e termed as probability of error which transmits through optical wireless channel can be determined by the formula given in [138]:

-

$$P_e = BER = \frac{1}{2}\text{erfc}\left(\frac{Q}{\sqrt{2}}\right) \quad (4.9)$$

Here erfc shows error complimentary function and it is evaluated.

Therefore, with the help of standard deviation and average values of the sampled values, the representation of eye height which is calculated in [56] is given by the expression given below: -

$$E_H = (\mu_1 - 3\sigma_1) - (\mu_0 - 3\sigma_0) \quad (4.10)$$

Here σ_1 and σ_0 are the standard values of sample 1 and sample 0. μ_0 and μ_1 are the average values of sample 0 and sample 1.

4.3 Principle

The major opinion of implementing optical based MDM technique is to enhance the capacity by sending polarized modes with the help of same wavelength and transmission can be done simultaneously over different mode division multiplexing. This system is proved beneficial as it provides efficiency in cost and approach of zero cross- relation can be achieved.

One of the most considerable approaches to incorporate mode division multiplexing has been explained against eavesdropping by using an expression which is used for estimating Eavesdroppers Probability of Interception for correct bits. Considering the impact of length of code to improve security, the total combinations which are required to be selected for achieving actual code wavelength for correct detection of codewords can be calculated by using the described formula in [56]:

$$T_C = n_{C_W} \quad (4.11)$$

Cross correlation presence helps to decrease the total combinations and fixes wavelength position.

$$T_{\lambda c} = n_{C_{\lambda c}} \quad (4.12)$$

When case of ZCCRW codes is considered then $\lambda_c = 0$. Then final cases as a resultant will be taken as: -

$$T_{Cr} = n_{C_W} - n_{C_{\lambda c}} \quad (4.13)$$

Thus, the total pulses considered are 50% of the available users that are totally present and it is given by the formula: -

$$P(p) = (1/2)^K \quad (4.14)$$

Whereas the probability of getting detection of right codeword is just half.

$$P(E) = 1/2\ (1/\ n_{C_W} - n_{C_{\lambda c}})\ (1/2)^K \quad (4.15)$$

The ZCCRW code which is proposed that has been compared with the codes reported such as DDW, RD and EDW with respect to features in security. It is noticed that ZCCRW code has less estimation probability in comparison with other given codes because larger length of codes would ultimately create large combinations for information detection for intruder. Also, due to $\lambda c=0$, larger will be denominator value and hence it will be difficult to detect correct error whereas cross relation present in other codes makes denominator value less which indicates that total combination needed to get correct data will also decrease, therefore chances of eavesdropping will increase.

Table: 4.1 Proposed work simulation parameters

PARAMETERS	**VALUES**
Data Rate	10Gbps
Capacity taken	100Gbps
No. of users	10
Input Power	0dBm
Modes of MDM	HG_{11-15}/LG_{11-15}
Line-code	MDRZ-DQPSK/CSRZ-DQPSK and DRZ-DQPSK
Comparison of SAC codes	DDW, ZCCRW, EDW and RD
Codes' weight	W=2 for DDW, W=5 for ZCCRW, ED and RD
Cross correlation	$\lambda_C=0$ for ZCCRW, $\lambda_C=1$ for RD, DDW and EDW
OWC distance	500km to 3000km
Transmission module of OWC	EDFA (gain20Db) +250km
Noise figure	4decibels
Number of Loops used	2,4, 6, 8,10 and 12

Also, because of various polarized modes presence, it is difficult to obtain correct detection of code word for intruder because it needs more investigation of linearly polarized modes. For enhancing security of different polarized modes, an expression has been derived using 4.15 and it is given below: -

$$P(E) = \frac{1}{2} r \, (1/ n_C W \quad - n_C \lambda_C) \, (1/2)^K \tag{4.16}$$

4.4 System set up

To attain the desired content, five users have been used to transmit the data over the modes LG/HG 21 to 25. For the proposed ZCCRW code, number of laser outputs required is 25 as per the equation: L=K*WR+K, for DDW code =6 according to L=k+1, for EDW code=20 as per the relation: L=K∗(W−1) and for RD code=12 according to L=K+2W−3. Different wavelengths are used and input is obtained by using continuous type of wave laser and these selective frequencies has been transmitted through the modes and then modulation of data will be done with 10 Gbps of data rate and input is passed through PRBS generator, spectrum compressed RZ-quadrated phase shift keying. Also, MDRZ-DQPSK stated as modified duo-binary DQPSK/DRZ-DQPSK can be used.

The proposed set-up consists of three different sections named as transmitter, channel and the receiver. The transmitter comprises of spatial laser which operates at 193.1 THz to generate final output. This system has been implemented with the help of Optisystem software-13. Frequency spacing of 50 Hz has been taken between the adjacent channels. Mode division multiplexing is considered as the best technology and efficient one for the proposed system to save cost by considering around half code matrix with respect to the complete users. For 10 users serving, LG/HG modes 11-15 has been carried and similar code of those five users is used to transmit the next modes i.e., 21-25. Data is multiplexed and transmitted with the help of optical wireless channel to the receiver. MZM modulator is used and single loop consists of pre-EDFA amplifier with gain value= 20 db and noise Fig. of 4 db and post EDFA amplifier with gain value- 20 db and noise Fig. of 4 db. Distance of 250 km for optical wireless channel has been taken. In the output section, PIN photodetector is employed followed by 3R regenerator and output is taken at BER analyzer and quality factor can be observed.

4.5 Results and Discussion

The main emphasis in this chapter is on communication security using mode division multiplexing of the satellites and ZCCRW code is constructed using SAC. Therefore, a comparison has been done between different SAC codes for the validation of proposed system using parameters like power, modes, coding and distance etc. In the proposed system, different modes have been implemented and compared like Hermite Gaussian modes and Laguerre-Gaussian modes by using different modulation techniques which includes CSRZ-DQPSK, MDRZ-DQPSK and DRZ-DQPSK modulation. This is done in order to select the optimal mode and calculate quality factor and BER w.r.t optical wireless communication distance.

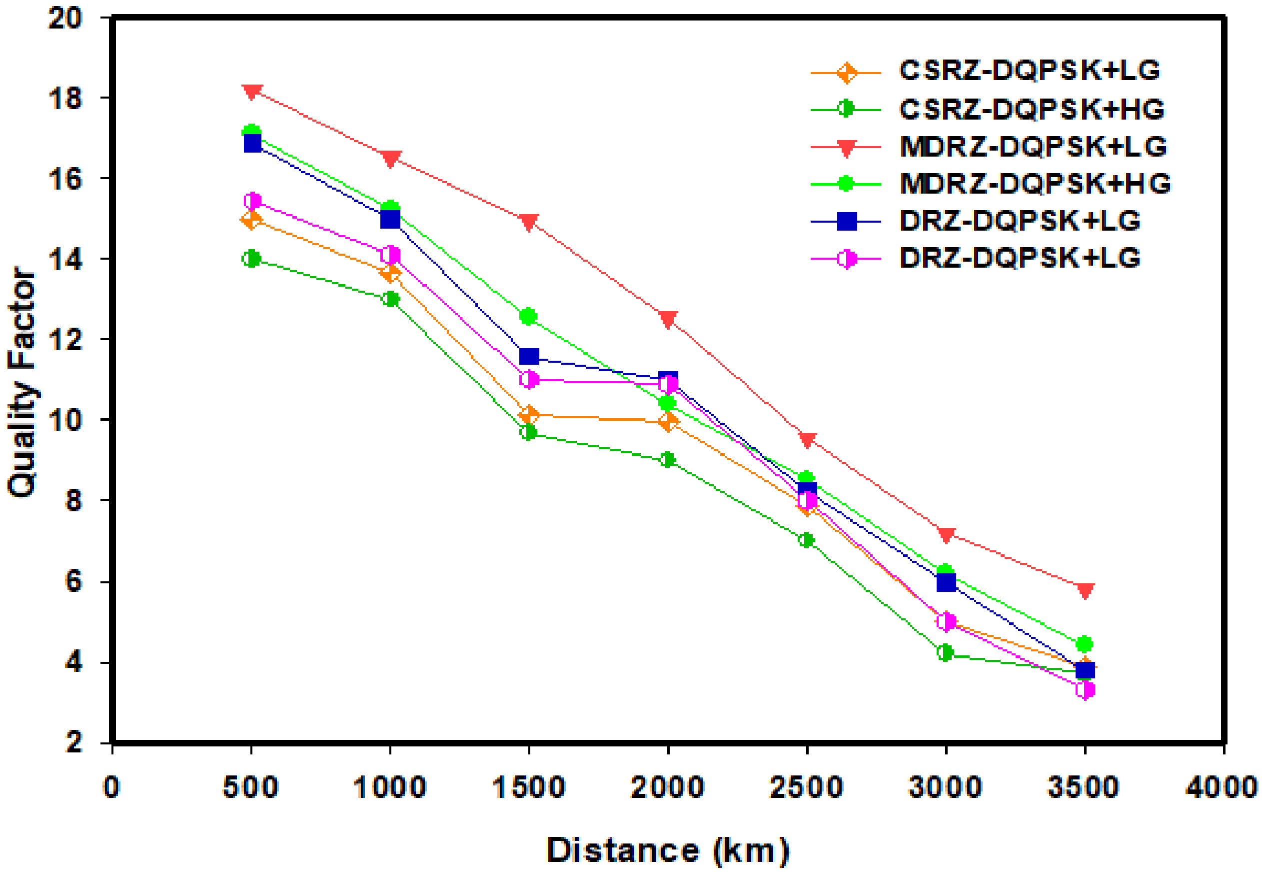


Fig. 4.3 Comparison of different Q-factors using different hybrid modulation with different link lengths and using LG, HG modes

Hybrid modulation has its benefits that it is useful in reducing inter-channel and intra-channel interference and ensuring better performance in comparison with single modulation because of extra phase shift. According to the observations and result, it has been concluded as given in Fig. 4.3 that MDRZ-DQPSK modulation is the best technique with the Laguerre-gaussian modes as it contains better tolerance and spectral efficiency in removing interferences as it contains hybrid phase shifts. CSRZ-DQPSK has given least results with the Hermitte-gaussian modes as it contains very less spectral efficiency.

Then the distance effect has been checked varying it from 500 to 3000 km and BER performance has been compared for the DDW, RD, EDW SAC codes and ZCCRW codes and it is shown in Fig. 4.4.

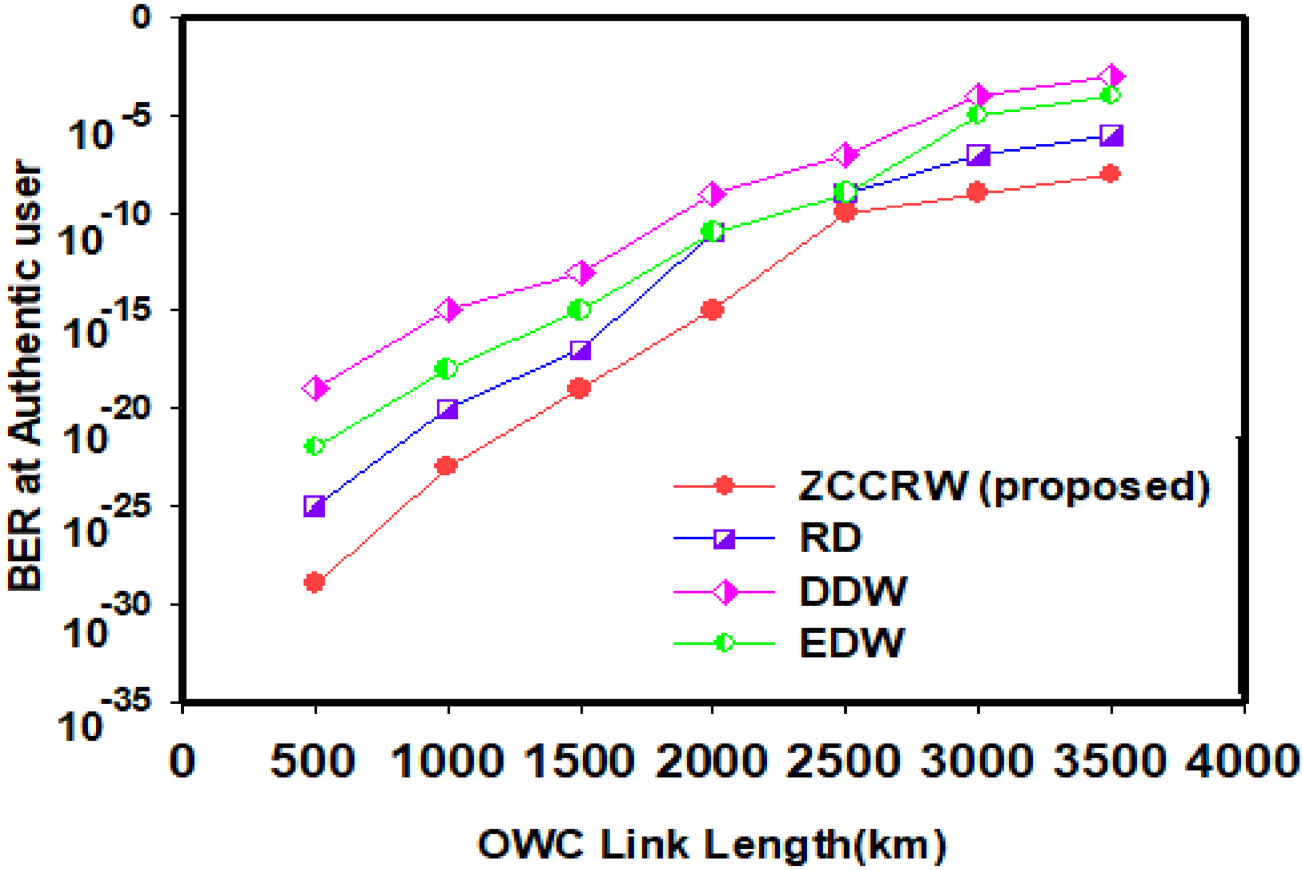


Fig. 4.4 Comparison of BER at reliable user with respect to link length of OWC for respective codes of SAC

When distance of optical wireless link increases, it will increase the BER at the authentic user and the environmental reasons like attenuation and scattering are responsible for it. Physical factors like shot and thermal noise in PIN diode and satellite pointing errors are also the factors which affect the performance. BER is least observed in ZCCRW code around 10^{-9} and distance will be around 3000 km.

It is observed that ZCCRW proposed code shows best performance as it contains least MAI. DDW code on the other side, given maximum errors at the authentic user which covers only around 2000 km having W=2 and it is evident that due to less W, there is less signal to noise ratio which results in maximum errors at the output end. The RD code has cross-correlation=1, so efficiency of RD code is good than that of EDW code as wavelengths are set at the locations which are distant in code matrix row. So, multiple access interference is less in case of RD code.

Eavesdropping is the major issue in coding as it disturbs the communication and it destroys the sensitive information. By increasing the length of code and to increase users' estimation of obtaining correct codeword at the spy decreases as there is more requirement of time for the eavesdropper to find required user combination. Even expression of P(E) has been derived where r parameter is introduced and it would indicate HG/LG Modes. This parameter is used to enhance combinations and increase the security of optical wireless communication systems. Fig. 4.5 shows P(E) at the eavesdropper w.r.t. users. Observations and results show that due to number of users, P(E) at eavesdropper will decrease and ZCCRW code has higher code length due to which requirement of combinations is more at eavesdropper and contains improved security.

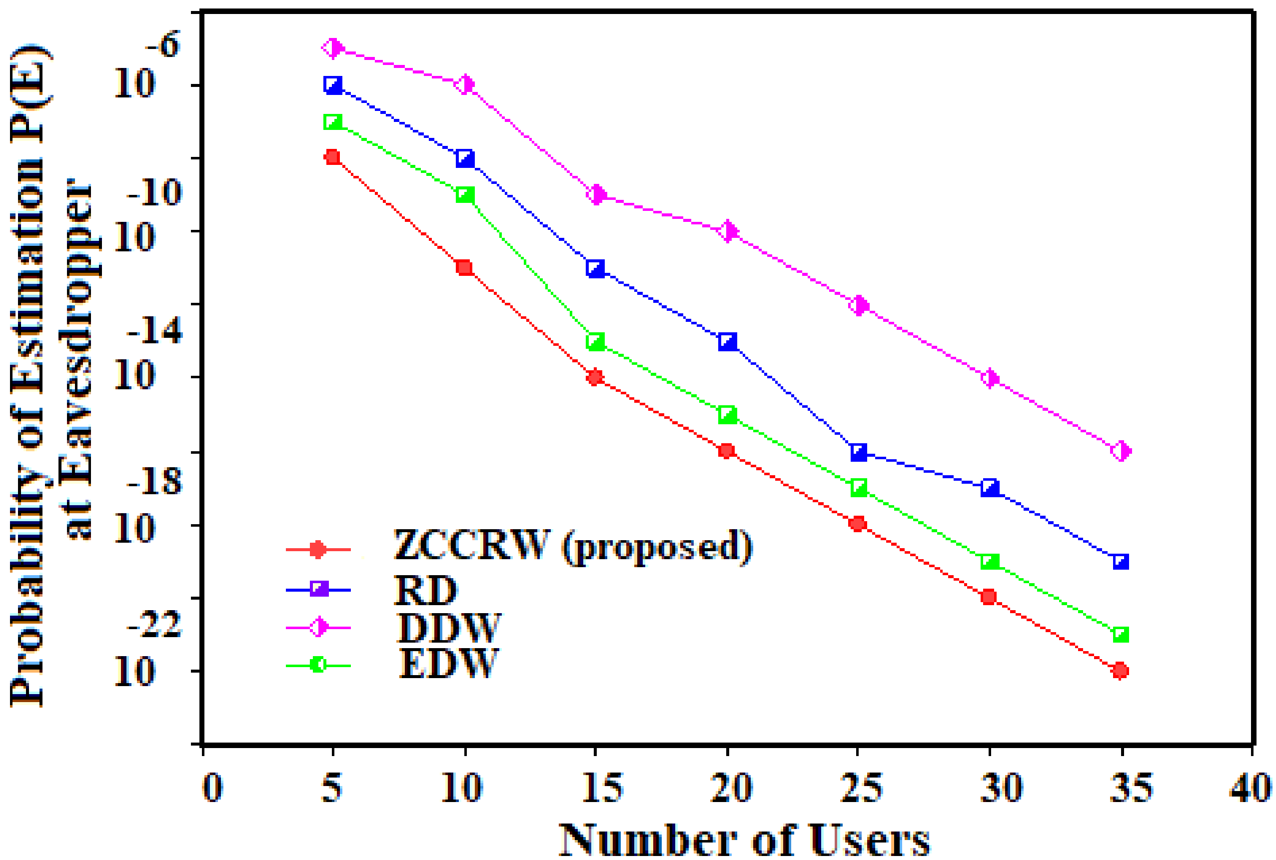


Fig. 4.5 Graph of P(E) Probability of estimation with respect to number of users

Also, SAC codes having cross correlation 1 and less code lengths have more vulnerability to eavesdropping. Therefore, there is more estimation of eavesdropping in case of RD codes and

DDW codes in comparison with ZCCRW code. Also, presence of W in EDW is consecutive and more prone to P(E) and in DDW code, P(E) is easiest as W= 2 as well as code length is minimum. Fig. 4.6 depicts correct bit receiving rate with respect to linewidth of laser for various MDM codes. Thus, band consisting of various sidebands is termed as laser linewidth. In other words, spectrum which is diverged across the desired output. With the increase in linewidth, the spectrum divergence multiplies with the carrier signal and it affects the exact bit rate with the errors which got in eavesdropping. Thus, by comparing results at output, analysis has been done that best results are achieved at linewidth of 300 MHz where security of system is highest and less value of bit rate is observed at spy with this linewidth.

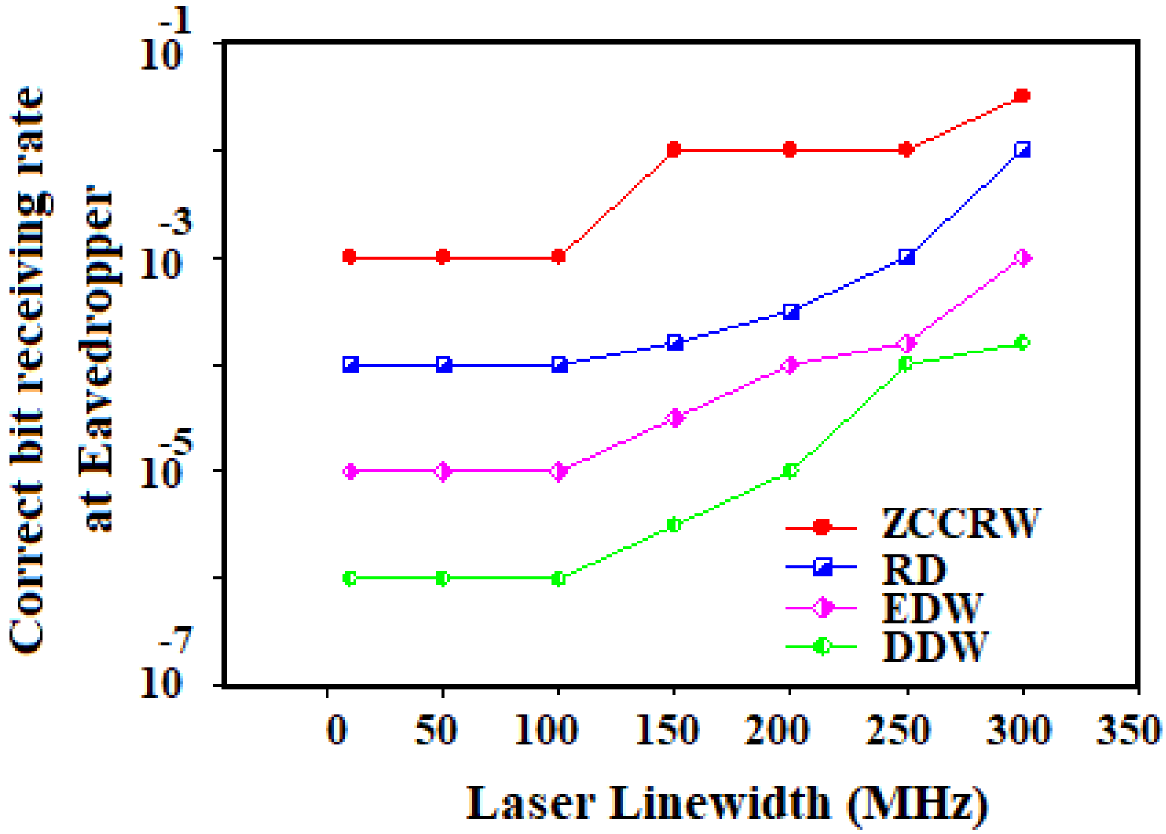


Fig.4.6 Graph of correct bit rate with respect to laser linewidth

So, out of four respective codes, proposed ZCCRW code provides minimum detection of errors at the eavesdropping which is around 10^{-2} which is followed by RD code, then EDW code and DDW code. The comparation of the results have been done of proposed ZCCRW coding with other SAC-OCDMA codes which is shown in Fig. 4.7. Extinction ratios varies from 15 upto 45 to check the value of jitter and it shows that from all codes which are investigated, RMS jitter value reduces when ER value enhances as jitter value is highest in case of DDW code because of less weight around 2 and cross-correlation of 1. Due to cross correlation absence, code matrix rows which are managed shows that optimal code is ZCCRW code.

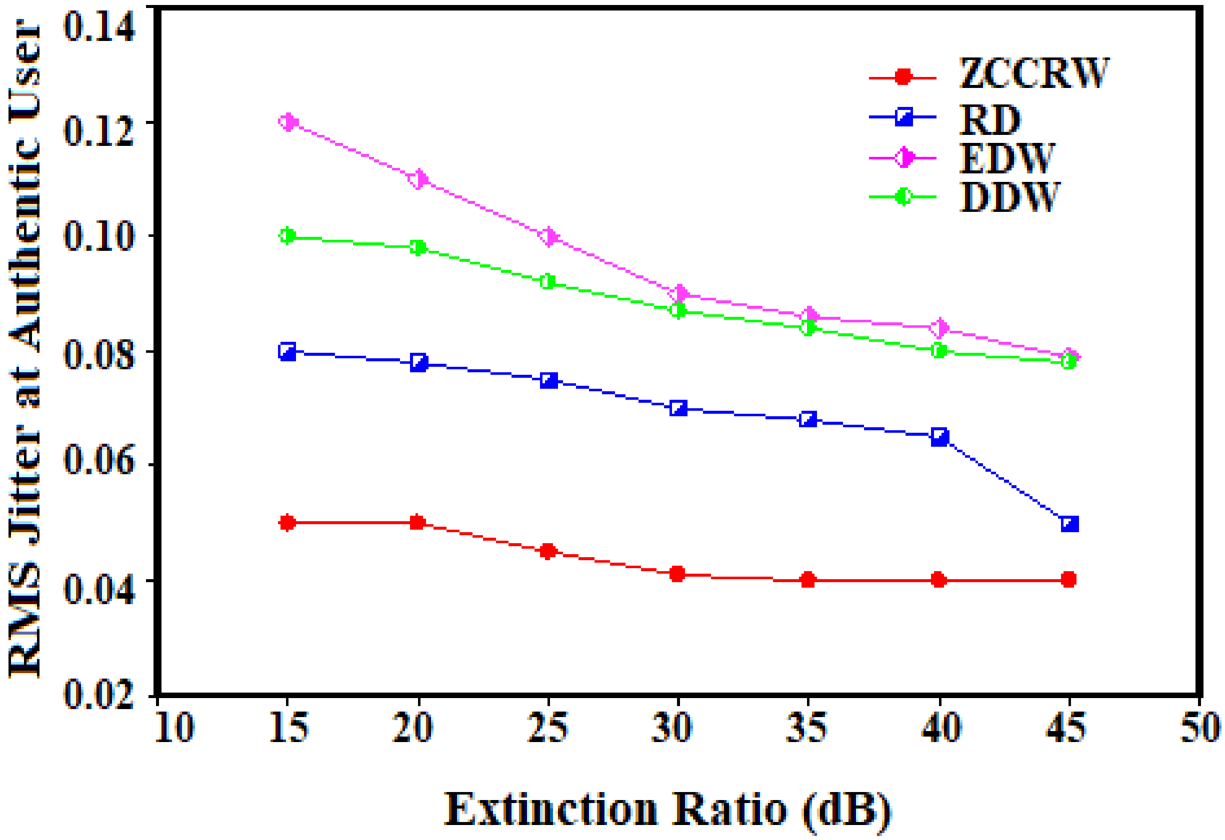


Fig.4.7 RMS jitter graph at the authentic user with respect to ER

4.6 Conclusion

In this chapter, a LEO based mode division multiplexing optical wireless communication system has been implemented to improve security and performance. Simulation is done in Optisystem software and results show that ZCCRW code has least susceptibility to eavesdropping which is evaluated using numerical study and mathematical expressions. Comparison has been done with the existing codes with respect to P(E), Bit error rate, RMS jitter and correct receiver BER when variation is done with linewidth, users, signal to noise ratio and distance.

Also, LG performance is varied with LP modes by combination with hybrid modulation and results revealed that MDRZ-DQPSK shows best performance with LG modes. Thus, to enhance security in Is-OWC systems, ZCCRW codes that are proposed can be implemented using MDRZ-DQPSK and LG modes, ZCCRW code is efficient code which contains best security features and least probability of estimation at eavesdropping in comparison with existing other codes of SAC.

CHAPTER 5

PERFORMANCE ANALYSIS OF MULTILEVEL DUAL POLARIZATION OCDMA

5.1 Introduction

This chapter supports the third objective of the thesis that is performance investigation in optical wireless communication system for multilevel dual polarization-based modulation. The proposed system investigates different codes and compares with the ZCCRW code. The set-up employs OCDMA code to enhance security and reduce MAI. Results revealed that quality factor of 29 and BER of 10^{-160} is obtained at a distance of 25000km. The content is presented in the following sections as described: in Section 5.2, system set-up is elaborated; Section 5.3 deals with the discussions and results achieved after simulation. In Section 5.4 conclusion is conferred.

5.2 Investigation of proposed ZCCRW code algorithm designed for security-enhancement

The recent technology i.e., IsOWC has the capability to provide high data rates, fast transmission speed, wide bandwidth and high channel capacity. It is observed that to combat the ever-increasing demand of fast services, RF and microwave links are insufficient. Hence, to meet them, 5G services and OCDMA based on inter satellite is preferred. With this technology, data rate of 100Gbps is obtained. The communication in the IsOWC system takes place at higher orbital level where the signal losses are almost equal to 0Db/km, hence leading to absence of attenuation losses [25]. Instead of these positive aspects, the performance of IsOWC system is not satisfactory owing to vibrations, equipment disturbances and noise radiations at the backend and eventually leading to failure of channel [51-53]. Therefore, it is mandatory to select operational wavelength range and modulation scheme to achieve best result for large range.

In addition to it, spectral efficiency and transmission speed are improved by integrating MDM technique [55]. MDM has the ability to transmit information from multiple channels simultaneously by using various spatial modes with the help of different eigen modes [58-59]. IsOWC is cost effective as large amount of data can be transferred at the same time and in small duration [122].

This technique employs LP modes that have light intensity profiles and eliminates issues such as crosstalk. MDM is considered better than existing techniques [75-76,78, 125-126] as it employs single laser which operates at different angles for different modes, thus resulting in cost efficient set-up. The most preferred technique for multiplexing data is OCDMA as it permits multiple users in single slot which minimizes bandwidth and component requirement [79, 107].

One of the major positive aspects of OCDMA based MDM is that it minimizes MAI and enhances security of the system [82]. Hence, it results in efficient usage of resources and code sequence [142]. Polarization modulation is considered one of the effective modulations as it eliminates the employment of radio resource domain in wireless communication [143]. There are incomparable features of this modulation like it is not impacted with noise and non-linear feature of the amplifier. Thus, it helps to improve the energy output and capacity of the channel. The polarization used by this modulation is of the carrier signal because its' parameters are being used widely these days [144].

The different polarization modulation techniques have been implemented, among which all have optical communication has the initial point. Likewise binary polarization shift keying has been discussed [145] in which orthogonally polarization is performed to obtain different bits which adds to higher security level. However, in this modulation method, the sudden switching of polarization results in large bandwidth requirement. So, to overcome this constraint, polarization modulation is employed which makes it spectral efficient. If amplitude and phase modulation are combined then polarization modulation leads to increase in power amplifier's energy efficiency further, it even operates in the non-linear distorted region.

The multilevel continuous dual polarization method not only offers continuous waveform but also provides regular polarization within a narrow bandwidth frame. In addition to it, it provides desirable symbol error rate and spectral performance [62]. In [146], the effect of greater distance and the pointing error on received optical power is depicted. This chapter will discuss about dual polarized OCDMA based IsOWC system by employing various codes.

5.3 System set up

The dual polarization modulation technique is employed on different codes and compared the performance with the proposed code i.e., ZCCRW. This code offers low bandwidth requirement, minimal MAI and simple code construction. The dual polarization outperforms when implemented in IsOWC system.

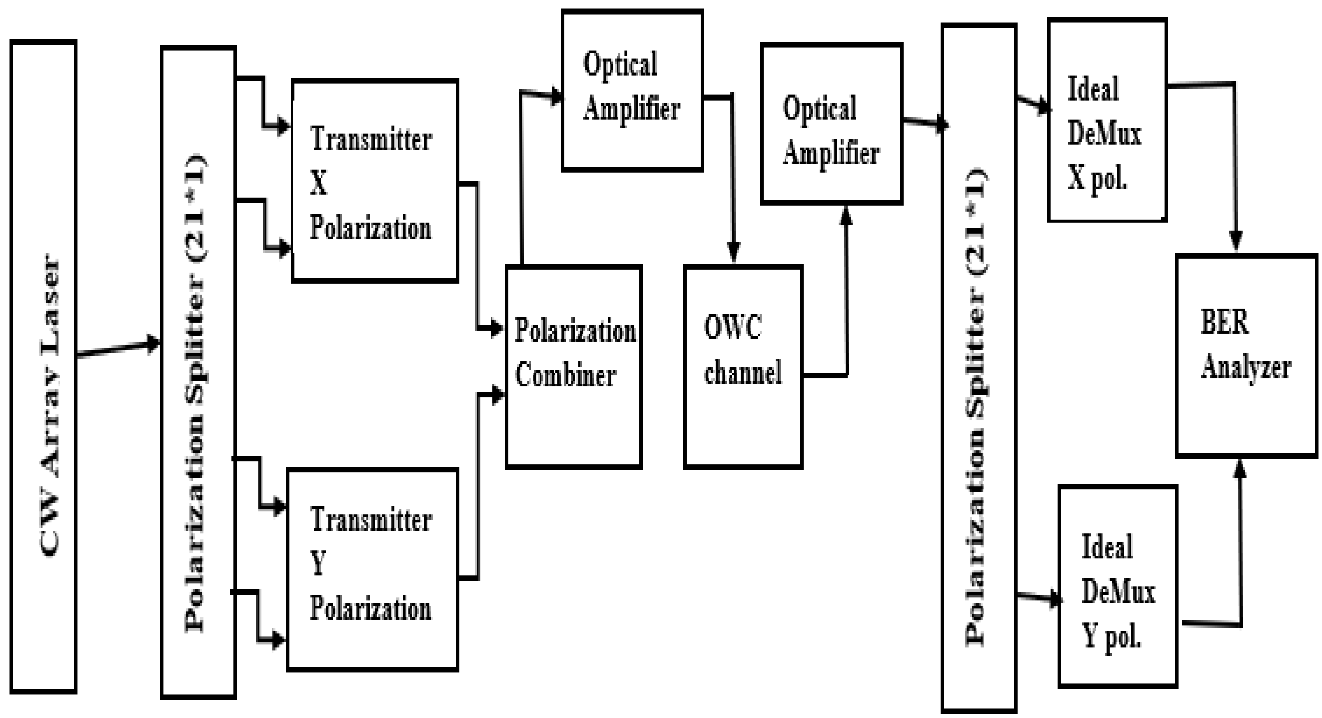


Fig.5.1 Proposed setup of dual polarized OCDMA based IS-OWC system

The simulation setup in Fig. 5.1 illustrates the impact of dual polarized OCDMA based IsOWC system when different combiners are used. In the presented set-up, continuous wave laser comprising of 193.1THz frequency and 30db input power is employed and simulated with Optisystem software. The system has 21 users leading to requirement of 21 input ports for each. The continuous wave lasers are present at the source and their output is provided to the polarization splitter. The basic function of polarization splitter is to divide the light into 2 different polarization namely transmitted X. and transmitted Y. The transmitter X. polarization comprises of 21 multiplexers to multiplex the signals obtained from the input source and further send to the demultiplexer. The output of demultiplexer is processed to seven WDM multiplexers which have three input ports individually. Here WDM is preferred over other multiplexing techniques because it can be easily configured and if required the channel capacity can be increased with an ease. Even the bit rate can be elevated for point-to-point systems.

Further the output is sent to PRBS generator that encrypts the data and simulates the streams of information. After that the output is encoded to various NRZ pulse generators. For modulating the data, Mach-Zehnder modulator is employed which has 30db value of extinction ratio.

After modulation, the data is sent to the ideal multiplexers. The Transmitter Y. polarization has the exact set up as that of the transmitter X. polarization. The polarization combiner is used for combining the output from the transmitter X. polarization and transmitter Y. polarization. Further, for amplification of the signal, optical amplifier is used.

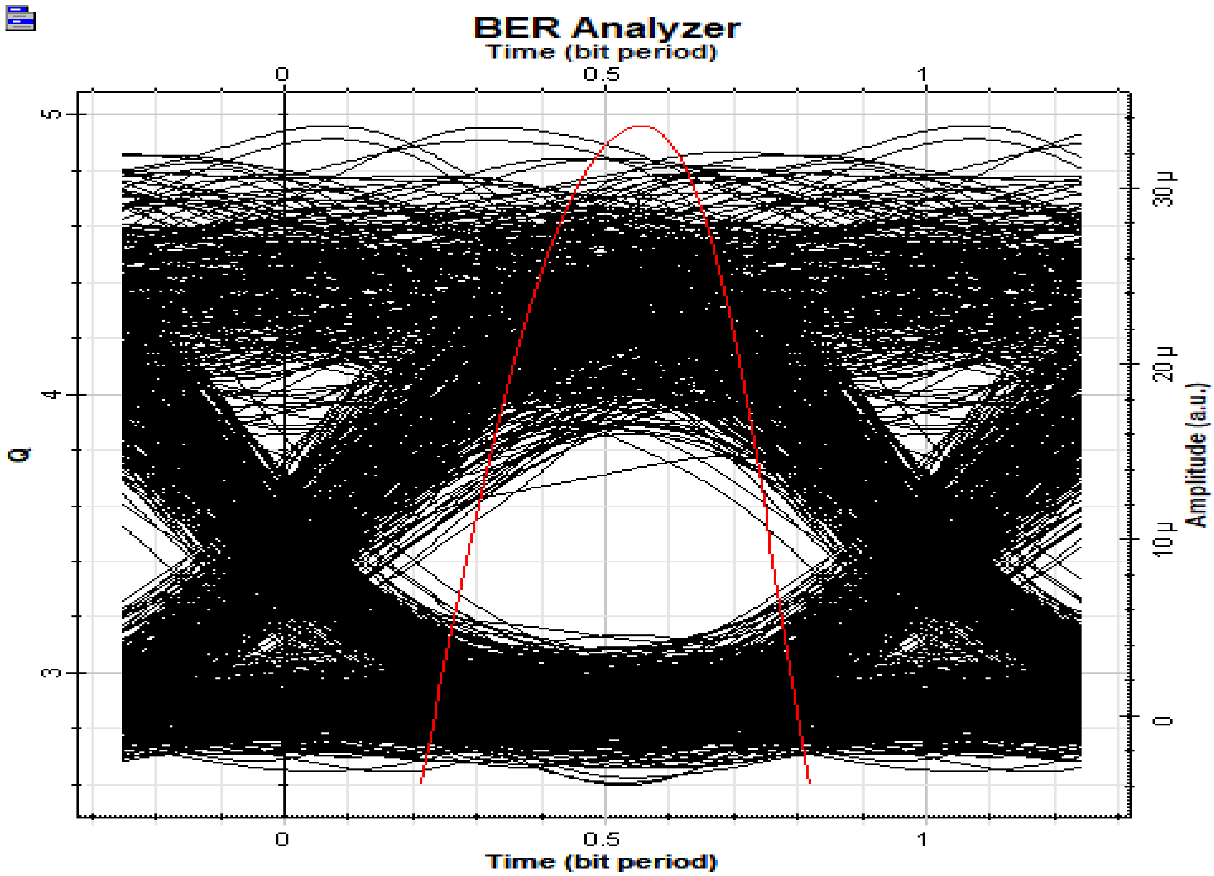
At the output end, demultiplexing of the output from optical amplifiers is done with the help of polarization splitter. The polarization splitter divides the data into ideal DeMux X. polarization and DeMux Y. polarization. On the output part, LP Bessel filter is employed to remove the unwanted data and only pass the desired signal at the optical receiver. This receiver operates as 3R regenerator. Finally, the output is read at the BER analyzer and eye diagrams are observed. The different performance parameters such as quality actor and BER is measured from the eye diagrams obtained at the analyzer. The different parameters employed for dual polarization IsOWC system simulation are listed in Table 5.1. These values are taken to obtain optimum quality factor and other performance parameters.

Table:5.1 Simulation component of ZCCRW-OCDMA based IS-OWC Set-up

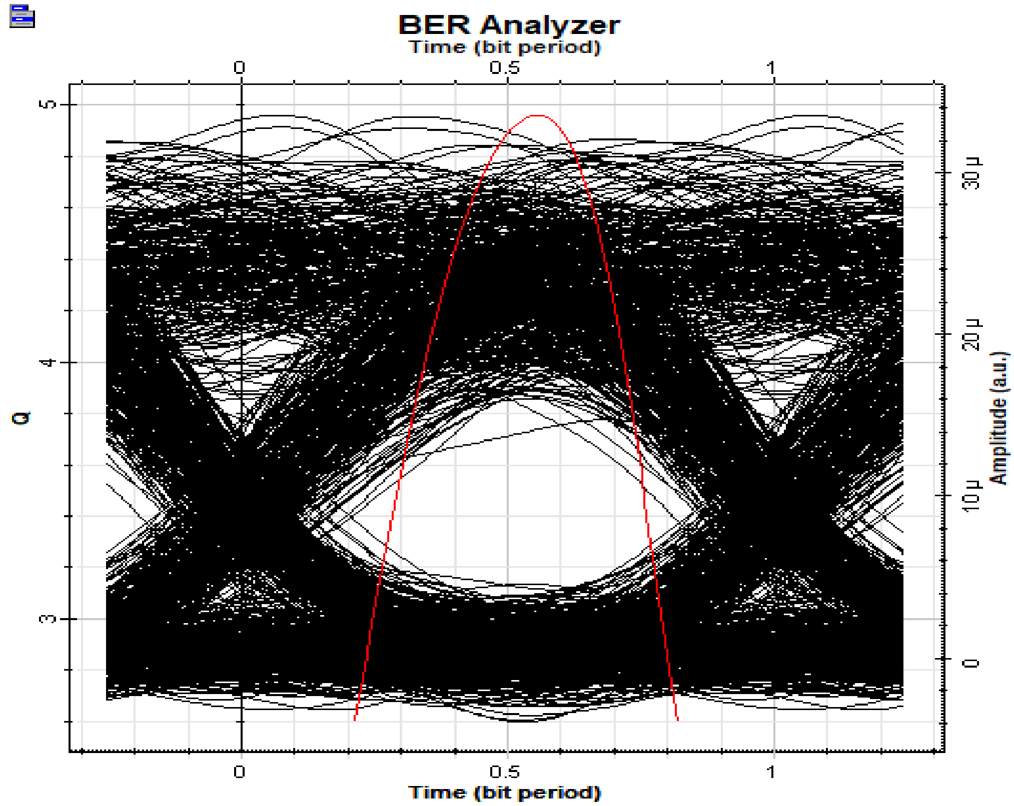
Simulation Parameters	**Values**
Frequency of CW laser	193.1 THz
Power	30 dBm
Frequency spacing	100 GHz
Gain of optical amplifier	30 db
Channel	OWC
Noise figure	4db
Wavelength of OWC channel	1550 nm
Range of OWC channel	3000 km
Bandwidth of Bessel optical filter	20 GHz
Bit rate	10 Gbps
No of input and output ports	21
Distance	25000 km

5.4 Results and Discussion

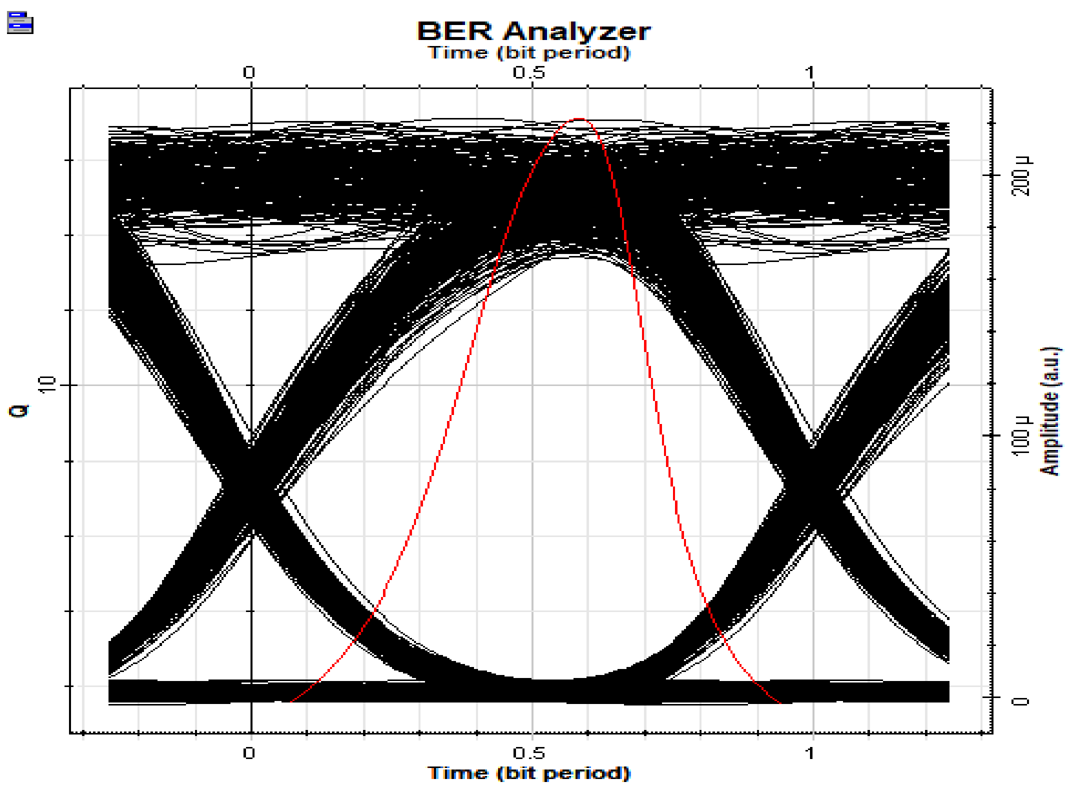
To evaluate the most efficient code from the existing and proposed code a comparison is done. A comparative analysis is done between ZCCRW and existing codes- MD and DDW code. The quality factor and BER have been calculated with respect to increase in the distance. After completion of simulation, the eye diagrams of DDW, MD and ZCCRW code have been taken into account for a range of 25000km as shown in Fig. 5.2.



(a)



(b)



(c)

Fig.5.2 Eye-diagram at a 25000 km distance for (a) DDW (b) MD (c) ZCCRW code

As per the observation, ZCCRW code has the highest quality factor leading to 29.2 followed by DDW with a value of 10.6 and MD having 8.7 value as depicted in Fig. 5.3. Also, the BER is 10^{-160} which is minimum in case of ZCCRW code because of error control feature. Fig.5.3 reveals the graph of comparison of three different codes with increasing IS-OWC distance from 15000-25000km.

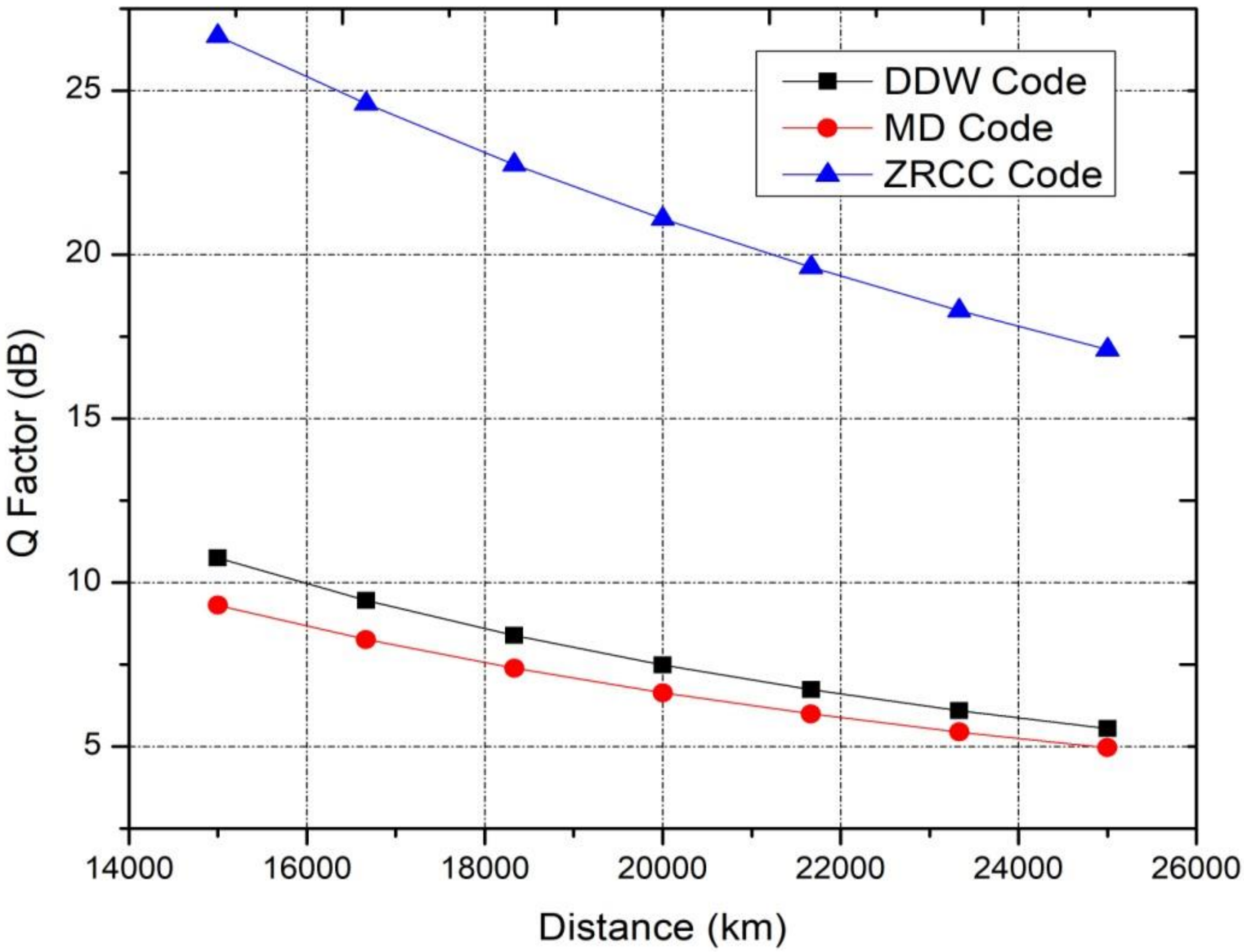
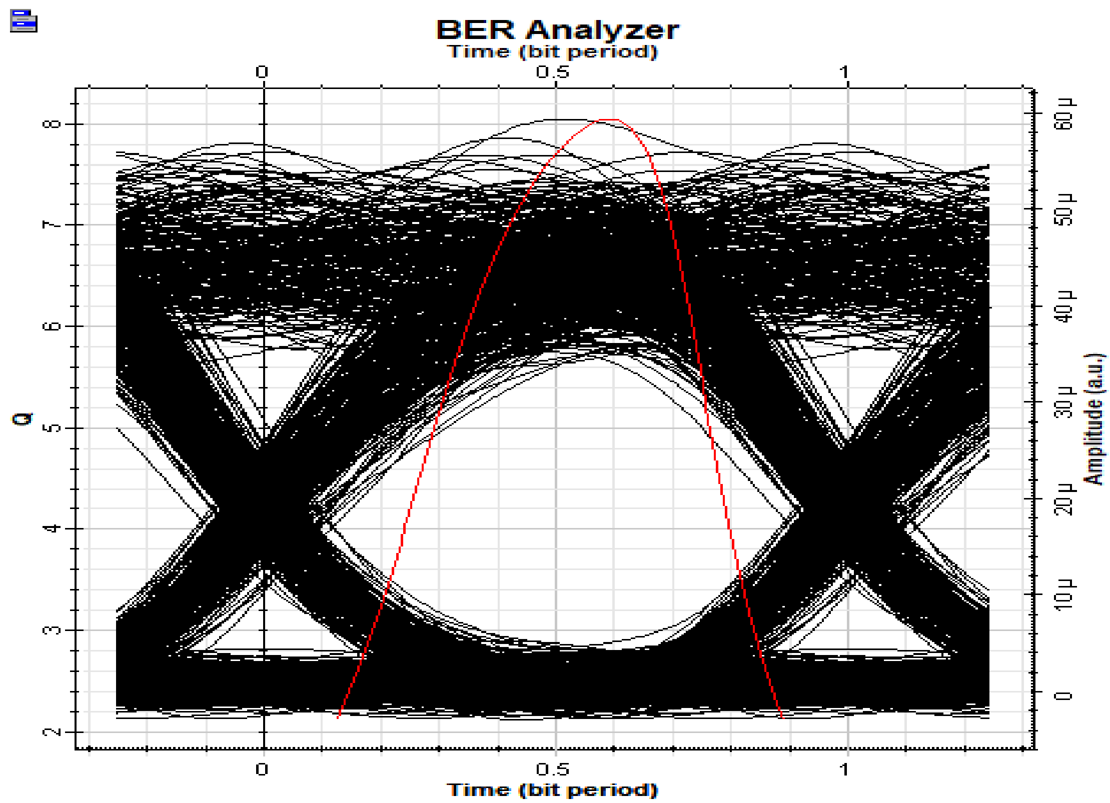
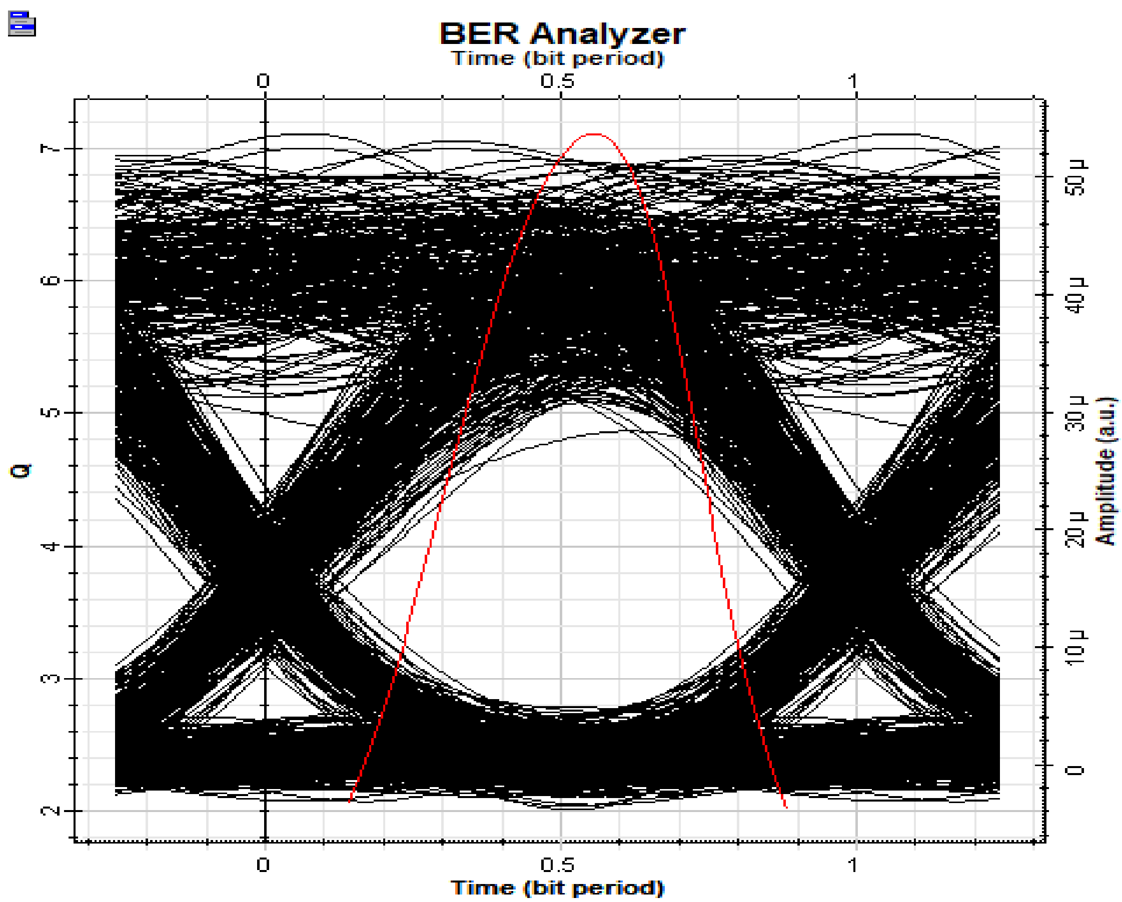


Fig. 5.3. Comparison of different codes with increasing distances

Also, to evaluate the efficiency of ZCCRW code by making the pointing errors present, receiver pointing error angle has been increased. The analysis is done at a distance of 25000km and the receiver's pointing error angle ranges from 1.0-2.6. The eye-diagram is obtained to find the value of BER as revealed in Fig. 5.4.


BER Analyzer
Time (bit period)
0
0.5
1
Q
2
3
4
5
6
7
8
Amplitude (a.u.)
0
10 μ
20 μ
30 μ
40 μ
50 μ
60 μ
Time (bit period)


BER Analyzer
Time (bit period)
0
0.5
1
Q
2
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4
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7
Amplitude (a.u.)
0
10 μ
20 μ
30 μ
40 μ
50 μ
Time (bit period)

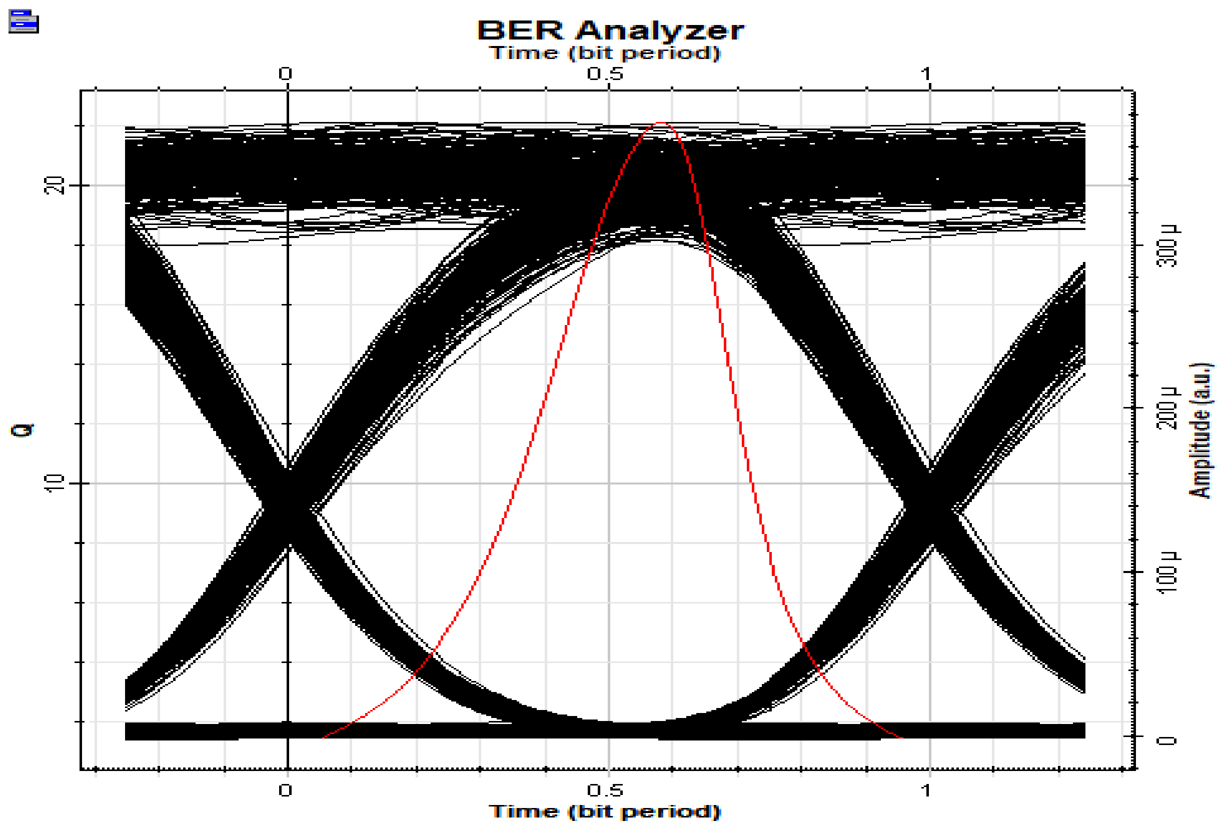

Fig.5.4 Eye diagram at 2.5 urad pointing error angle (a) DDW (b) MD (c) ZCCRW code

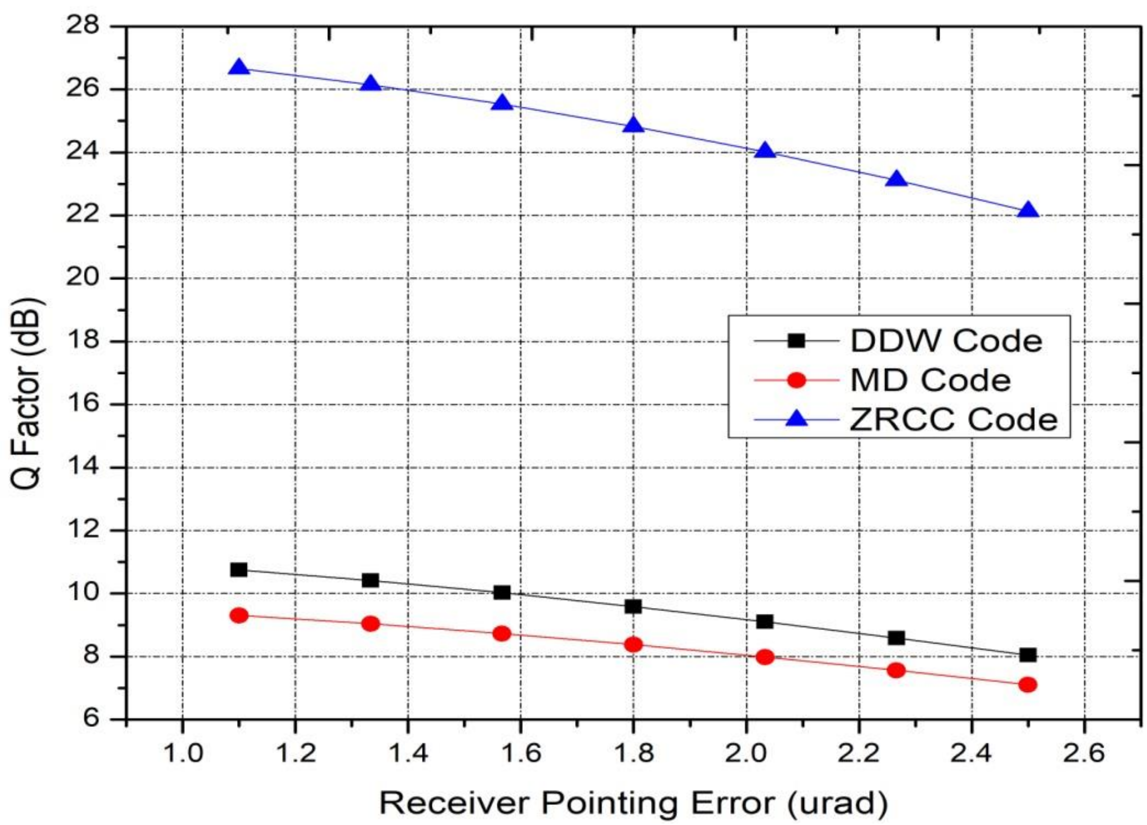

Fig. 5.5. Quality Factor versus Pointing error

Further, to note the value of quality factor for the different codes, the receiver's error is varied as depicted in Fig. 5.5. The results obtained revealed that maximum quality factor is achieved in case of ZCCRW code amounting to 27, followed by DDW code and MD code. The minimum Q-factor was achieved in MD code i.e., 8.

The system's performance is observed by noting the impact of distance on the receiver optical power. When the distance is varied from 15000km to 25000km the power corresponding to it ranges from 7dBm to 3dBm in case of ZCCRW code. The ROP is least for MD code followed by DDW code reaching upto -3.5 dBm and -2.8dBm respectively as depicted in Fig. 5.6.

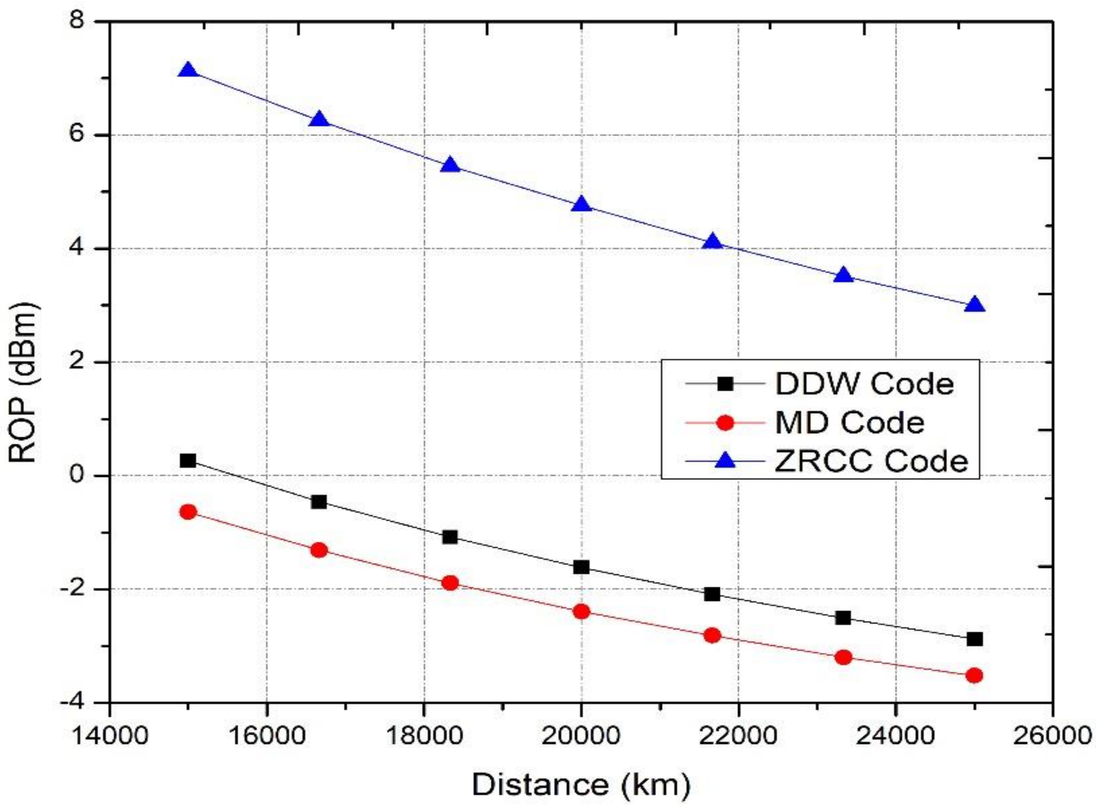

Fig. 5.6. Received optical power versus distance

The ROP is reduced maximum in case of MD code followed by DDW code due to misalignment of pointing angle at receiver side. Fig. 5.7 reveals that the ZCCRW code has the highest value of output power i.e. 3dBm when pointing error is 1.1μrad and it reduces to 1dBm as the error increases to 2.5μrad .

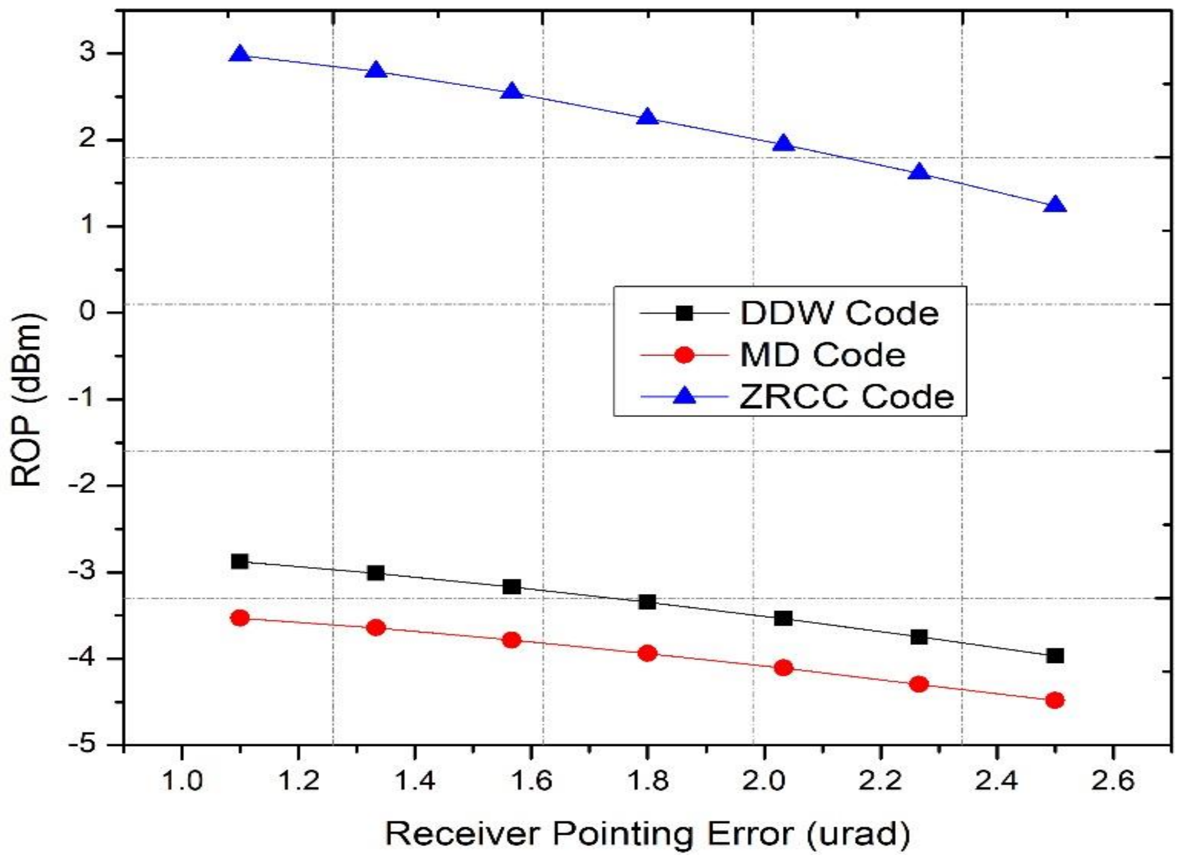

Fig. 5.7. Received optical power versus pointing error

5.4 Conclusion

The simulation results of ZCCRW code, DDW code and MD code in dual polarization OCDMA technique in IsOWC based transmission system are presented. To obtain the desired output, transmitter X. polarization and transmitter Y. Polarization subsystems are employed for distance of 25000km with 10Gbps data rate and input power 30dBm. A comparison is done between the three codes to analyze the efficiency of the newly formed code. The impact of distance and receiver pointing error angle on these codes has been discussed.

It is concluded that ZCCRW code outperforms as compared to DDW and MD code. The results revealed that quality factor 29 and BER 10^{-160} is achieved in case of ZCCRW code in contrast to the other codes. The value of Q factor was just 10.6 for DDW code owing to MAI and 8.7 for MD code because of high SNR. The receiver optical power for proposed ZCCRW code is 3dBm corresponding to 1.1 µrad value of pointing error.

CHAPTER 6

CONCLUSION, RECOMMENDATIONS AND FUTURE SCOPE

6.1 Conclusion

This thesis represents the study of inter satellite optical wireless communication system based on lower earth orbit. The main motive of this thesis is to provide a detailed analysis of the properties, features, system parameters and the factors impacting performance of IS-OWC system. In today's era, the ever-increasing need of high-speed network requires high tech techniques in optical wireless communication system. As per the requirement, IS-OWC is an invaluable technique to cope with needs of the present times. The multiplexing of differently polarized modes to support multiple users is an efficient way to overcome the limitation of data traffic. The lack of development in this area results in various difficulties because there is overlapping of signals caused by simultaneous transmission of data. The work reported in the thesis comprises of two major areas: Performance of IS-OWC system with zero cross correlation and security enhancement to avoid eavesdropping. The impact of cross correlation in optical wireless communication system is discussed. For eliminating cross correlation in IS-OWC system, different existing one-dimensional codes (MD code, Double diagonal weight, random diagonal code and EDW code) are discussed. Further, an enhanced code than the existing ones is presented that also improved bandwidth efficiency. The effect of mode division multiplexing with various types of spatial modes (LG_{11-15}/HG_{11-15}) for improving the capacity of the system is analysed. Also, the security leakage issue due to lack of dual polarization has been discussed mathematically. It can be determined that overlapping among the users caused cross correlation that eventually degraded the system performance. Hence, it is observed that to achieve minimum MAI and BER, users are sent at different modes.

This thesis depicted that the different linearly polarised modes enhanced security feature and avoided cross correlation. The comparison of BER values with and without FEC is made for the proposed code and the other present codes. The results depict that for a distance upto 4000km, the values achieved with FEC are better than without FEC due to error control. The relation between extinction ratio and linewidth is observed by analysing the performance of SAC codes. The extinction ratio is highest for ZCCRW code reaching to 47.9 for a distance of 2500km owing to absence of cross correlation. The MAI is observed for different number of users by fixing source power at 0dBm. Although MAI needs to be zero for ZCC codes but owing to nonlinear effects and combined power, there is presence of minimum MAI in ZCCRW code too. The data rate is increased on decreasing the time slot leading to high error rate in OCDMA codes. Therefore, quality factor of decreases from 16.5 to 9.8 as the chip size decreases from 0.1 ns to 0.02ns. The comparison of eye height with respect to received power for different OCDMA codes is made by taking two algorithms into consideration. The results achieved after calculation showed that chi-squared algorithm based ZCCRW code has outperformed than all other codes due to controlled code length and absence of cross correlation. The work is validated to observe the impact of number of users in terms of SNR on ZCCRW code. The parameters used for simulation operated on 1550nm wavelength for a distance of 2500km. The ZCCRW gave better performance with code weight = 2 and length of code = 14.

It revealed that multilevel dual polarization OCDMA based modulation at 1550nm wavelength with low input power covering distance upto 25000km. It is perceived that for the newly proposed code i.e., ZCCRW code, QFobtained is 16.5 for chip size accounting to 0.1 ns, and at a distance of 4000 km, BER 10^{-9} is obtained by employing forward error correction (FEC) method. It is also examined that by using different polarised modes, the eavesdropping can be minimized. The concept of mode division multiplexing is also explained thoroughly. This thesis deals with the impact of hybrid modulation to observe modulation effect by combining Hermite Gaussian (HG) and Laguerre-Gaussian (LG) mode. The positive aspect of using hybrid modulation is that it minimizes the interference which includes interchannel and intrachannel, in addition to it, provide high performance in comparison to single (with no hybridization) modulation because of additional phase shifting. The effect of distance ranging from 500-3000 km in LEO orbit is checked for authentic users in terms of BER for ZCCRW, ED, RD and DDW SAC codes.

A new expression for P (E) has been derived in which a new parameter ‘r’ has been presented which denotes the number of Hermite Gaussian and Laguerre-Gaussian modes. Further it is noted that presence of multiple users at eavesdropper decreases the chance of P (E). In addition to it, in codes like ZCCRW the greater code length leads to more combinations at the eavesdropper thus leading to higher security level. The correct bit receiving rate in contrast to laser linewidth on the basis of system designed for MDM SAC codes is depicted. It is seen that at 300MHz linewidth maximum security is attained because the correct bit rate is minimum at this value. In the MZM, the extinction ratio is varied from 15 to 45 to evaluate the jitter value. It is analysed that RMS jitter lowers as the ER value increases, further DDW code has maximum jitter value owing to unity cross correlation and low weight.

6.2 Recommendations

- The need of high-speed data is increasing tremendously owing to increase in internet traffic caused by the cell phones and multimedia; leading to more availability of capacity in the existing communication systems. Thus, to combat the demand of data, the ideal multiple access techniques employed in optical wireless communication systems is OCDMA technology. This technique has distinct features like permitting multiple users simultaneously over the same spectrum.
- Optical wireless communication systems are much more immune to interference. These systems provide huge data rates upto Gbps. This system supports unlimited bandwidth range and in the communication systems, the amount of data increases when the bandwidth is increased.
- Featuring unique simple system, minimum power consumption and minimized interference; the proposed ZCCRW code set-up can be used in IS-OWC systems to fulfill the high data speed requirement with enhanced bandwidth.
- The proposed security enhanced mode division multiplexed system is recommended in inter satellite communication, ground to satellite communication, cellular technology and military areas. All these areas have security leakage as a major concern.
- For transmitting data with higher security levels, linearly polarized modes can be used in which a greater number of combinations are required to breach the data. Hence, eavesdropping can be avoided using dual polarization method.
- For elimination of cross correlation in inter satellite communication the proposed code has the ability to achieve ideal response with other optimization parameters.

6.3 Scope for future work

- The research on Inter satellite optical wireless system is still an open area which requires a deeper insight into the simulation parameters to meet the ever-increasing demand of high-speed data and more bandwidth.

- In the coming years, not only Q factor be increased but also the number of polarized modes can be increased. Thus, increment of modes is the main point which can be thought of in the coming years. This will enhance the capacity of the system, increase the data rate, improved SNR and improve security.
- As the number of users and weight of code variation impacts the bit error rate and the quality factor of the wireless system therefore codes which support large number of users simultaneously can be developed. Such type of codes will reduce multiple access interference while transmission of data through the satellites. These codes can be recommended in military applications.
- Many codes can be formed by varying the values at diagonal and non-diagonal places for achieving zero cross correlation and higher bandwidth. Hence, it is gaining attention in latest telecommunication and space communication.
- With further optimization the proposed ZCCRW code can be employed for analyzing the security breach levels even at larger scale with fast speed.
- By incorporating enhanced dual polarization technique along with modulation our IS-OWC system can be deployed for various applications.

REFERENCES

[1] Heine, Kämpfner, R. Czichy, R. Meyer, M. Lutzer, “Optical Inter-Satellite Communication Operational”, The2010 Military Communications Conference - Unclassified Program - Systems Perspectives Track, IEEE, 2010.

[2] Toyoshima, K. Takizawa, T. Kuri, W. Klaus, M. Toyodo, H. Kunimori, T. Jono, Y. Takayama, M. Mokuno and K. Arai, “Results of Ground-to-Space Optical Communications Experiments using a Low Earth Orbit Satellite”, Lasers and Electro-Optics Society, 19th Annual meeting of IEEE,2006.

[3] Ghassemlooy and W. O. Popoola, “Terrestrial Free-Space Optical communications”, UK: Optical Communications Research Group, NCR Lab, 2010.

[4] Sun, “Satellite Networking-Principles and Protocol”, UK: John Wiley & Sons, 2005.

[5] Hashim, F. D. Mahad, S. M. Idrus and A. S. M. Supaat, “Modeling and Performance Study of Inter Satellite Optical Wireless Communication System”, Photonics (ICP), International Conference of IEEE,2010.

[6] K. P. Kaur, R. Randhawa, and R. S. Kaler, “Performance analysis of WDM-PON architecture using different receiver filters,” *Optik*, vol. 125, no. 17, pp. 4742- 4744, 2014.

[7] Q. M. Ngo, S. Kim, S.H. Song, and R. Magnusson, “Optical bistable devices based on guided-mode resonance in slab waveguide gratings”, *Optics Express*, vol. *17, no.* 26, pp. 23459-23467, 2002.

[8] Z. Ghassemlooy, S. Zvanovec, W. O. Popoola and J. Perez, “Optical Wireless Communication Systems”, *Optik-International Journal for Light and Electron Optics, Elseveir*, vol. 151, pp. 1-6,2017.

[9] D.K. Borah and D. G. Voelz, “Pointing Error Effects on Free-Space Optical Communication Links in the Presence of Atmospheric Turbulence”, Journal of Lightwave Technology, IEEE, vol. 27, No. 18, pp. 3965-3973,2009.

[10] X.Z. Gao, X. Wang, and S.J. Ovaska, “Uni-modal and multi-modal optimization using modified harmony search methods”, *International Journal of Innovative Computing, Information and Control*, vol. *5,* no. 10, pp. 2985-2996, 2009.

[11] G.C. Yang and W.C. Kwong, “Prime Codes with Applications to CDMA Optical and Wireless

Networks," Norwood, MA: ArtechHouse,2002.

[12] D.E. Leaird, Z. Jiang and A. M. Weiner. "Experimental investigation of security issues in OCDMA: a code-switching scheme", *Electronics letters,* vol. 41, no. 14 2005.

[13] P.R. Prucnal, "Optical Code Division Multiple Access: Fundamentals and Applications," Boca Raton, *FL: Taylor &Francis Group,*2006.

[14] P.R. Prucnal, M.A. Santoro, T.R. Fan, "Spread spectrum fiber-optic local area network using optical processing," *J. Lightwave Technol.*Vol.4, no.5, pp.547–554,1986.

[15] M. Salah, A.M. Alhassan, "Evaluation of Different Codes in SAC-CDMA System", *Evaluation,* vol. 3, no. 1, pp. 34-37, 2017.

[16] A. Nirmalathas, P.A. Gamage, C. Lim, D. Novak, R. Waterhouse, "Digitized radio-over-fiber technologies for converged optical wireless access network", *Journal of Lightwave Technology,* vol. *28, no.* 16, pp. 2366-2375, 2010.

[17] I.A. Ashour, S. Shaari, P.S. Menon, H.A. Bakarman, "Optical code-division multiple-access and wavelength division multiplexing: hybrid scheme review", *Journal of Computer Science,* vol. 8, no. 10, pp. 1718-1719, 2012.

[18] R. Kaur, H. Kaur, "Comparative analysis of chirped, AMI and DPSK modulation techniques in IS-OWC system", *Optik*, vol. 154, pp. 755-762, 2017.

[19] A. Amphawan, Y. Fazea, H. Ibrahim, "Investigation of channel spacing for Hermite-Gaussian mode division multiplexing in multimode fiber", In *2015 IEEE 11th international colloquium on Signal processing & its applications*, pp. 34-39, 2015.

[20] A. Alipour, A. Mir and A. Sheikhi, "Ultra High-Capacity Inter-Satellite Optical Wireless Communication System using Different Optimized Modulation Formats", *Optik-International Journal for Light and Electron Optics, Science Direct*, vol. 127, No. 19, pp. 8135-8143, 2017.

[21] S.K. Liao, H.L. Yong, C. Liu, G.L. Shentu, D.D. Li, J. Lin and J.W. Pan, "Long-distance free-space quantum key distribution in daylight towards inter-satellite communication", *Nature Photonics*, vol.11, no. 8, pp.509-513, 2017.

[22] S. Chaudhary and S. Sharma, "Role of Turbulences in WDM-Polarization Interleaving Scheme based Inter-Satellite Communication System", *International Journal of Computer Applications*, vol. 104, no. 10, pp. 1-7, 2014.

[23] N. Kumar, "2.50Gbit/s Optical Wireless Communication System using PPM Modulation Schemes in HAP-to-Satellite Links", *Optik-International Journal for Light and Electron Optics, Elsevier,* vol. 125, no. 14, pp. 3401-3404,2014.

[24] V. Kumar and A. Kaur, "Challenging Issues in Inter-Satellite Optical Wireless Systems (IsOWC) and its Mitigation Techniques", *Proceedings of International Conference of Advances in Communication, Network and Computing*, vol. 1, pp. 52-54, 2013.

[25] V. Sharma and N. Kumar, "Modeling of 2.5 Gbps-intersatellite link (ISL) in inter-satellite optical wireless communication (IsOWC) system", *Optik*, vol. 124, no. 23, pp.6182-6185, 2013.

[26] S. Singh, R. Kaur, A. Singh and R.S. Kaler, "Novel security enhancement technique against eavesdropper for OCDMA system using 2-D modulation format with code switching scheme", *Optical Fiber Technology*, vol.22, pp.84-89, 2015.

[27] S. S. Sodhi, and R.S. Kaler, "Receiver sensitivity improvement using polarization-insensitive semiconductor optical amplifier", *Optical Engineering*, vol. *45, no.* 6, pp. 065007, 2006.

[28] B. Patnaik and P. K. Sahu, "Inter-satellite Optical Wireless Communication System Design and Simulation", *IET Communications, IEEE,* vol. 6, no.16, pp. 2561-2567, 2012.

[29] NHM Noor, W. A. Khateeb and A. W. Naji, "Experimental Evaluation of Multiple Transmitters/Receivers on Free Space Optics Link", *Student Conference on Research and Development*, *IEEE*, pp. 128-133, 2011.

[30] NHM Noor, A. W. Naji and W. A. Khateeb, "Performance Analysis of a Free Space Optics Link with Multiple Transmitters/Receivers", *IIUM Engineering Journal,* vol. 13, no. 1, 2012.

[31] S. Revathi and G. Aarthi, "Performance Analysis of Wave Length Division and Sub Carrier Multiplexing using Different Modulation Techniques", *International Journal of Engineering and Research Applications,* vol. 1, no. 2, pp. 317-320,2012.

[32] X. Liu, "Optimization of Satellite Laser Communication Subject to Log-Square-Hoyt Fading", *Transactions on Aerospace and Electronic Systems, IEEE,* vol. 47, no. 4, pp. 3007-3012,2011.

[33] K. Wang, A. Nirmalathas, C. Limand E. Skafidas, "High speed 4× 12.5 Gbps WDM optical wireless communication systems for indoor applications", *In National Fiber Optic Engineers Conference (p. JWA081). Optica Publishing Group. Conference and Exposition and the National Fiber Optic Engineers Conference, IEEE*, 2011.

[34] L. Qin, H. Yin, W. Liang, Z. Wang and A. Xu, "Security performance analysis of an M-code keying OCDMA system", *Photonic Network Communications*, vol.*15, no.* 1, pp.19-24, 2008.

[35] Z. Sodnik, B. Furch and H. Lutz, "Optical intersatellite communication", *IEEE journal of*

selected topics in quantum electronics, vol.*16, no.* 5, pp.1051-1057, 2010.

[36] HA Abdul-Rashid, F.M. Abbou, H.T. Chuah, M.B. Tayahi, M.T. Al-Qdah and S. Lanka, "System Performance Optimization in SCM-WDM Passive Optical Networks in the Presence of XPM and GVD", *IEEE*, vol. 10, no. 9, pp. 670-672, 2006.

[37] N.H.M. Noor, A.W. Naji and W. A. Khateeb, "Theoretical Analysis of Multiple Transmitters/Receivers on the Performance of Free Space Optics (FSO) Link", *International Conference on Space Science and Communication (Icon Space), IEEE*, pp. 291-295, 2011.

[38] K. Karim, Y. Yaicheand M. Banslama, "Optimization of Transmitter Aperture by Genetic Algorithm in Optical Satellite", *International Journal of Information and Communication Engineering*, vol. 1, no. 1, 2007.

[39] A. W. Young, J. E. Sluz, J. C. Juarez, M. B. Airola, R. M. Sova, H. Hurt, M. Northcott, J. Phillips, A. McClaren, D. Driver, D. Ablson and J. Foshee, "Demonstration of High Data Rate Wavelength Division Multiplexed Transmission over a 150 km Free Space Optical Link", *Military Communications Conference, MILCOM, IEEE*, pp. 1-6,2007.

[40] M. Guelmann, A. Kogan, A. Kazarian, A. Livne, M. Orenstein and H. Michalik, "Acquisition and Pointing Control for Inter-Satellite Laser", *Transactions on Aerospace and Electronics Systems*, *IEEE*, vol. 40, no. 4, pp. 1239-1248,2004.

[41] M. Pfennigbauer and W.R. Leeb, "Optical Satellite Communications with Erbium Doped Fiber Amplifiers", *Space Communications*, vol.19, no.1, pp. 59–67, 2003.

[42] Su Yuwei and Sato Takuro Sato, "A Key Technology for Standarising Outdoor Optical wireless Communication", *ICT Express*, vol.3, no.7, pp. 62-66, 2017.

[43] S. Mostafa, AE.N.A. Mohamed, F.E.A. El-Samie, A.N.Z. Rashed, "Performance Evaluation of SAC-OCDMA System in Free Space Optics and Optical Fiber System Based on Different Types of Codes", *Wireless Personal Communications*, vol. 96, pp. 2843-2861, 2017.

[44] A. Alyan, S. A. Aljunid, M. S. Anuar and C. B. M. Rashidi, "SAC-OCDMA over Indoor Optical Wireless Communication (OWC) System based on Zero Cross Correlation (ZCC) Code", In *Materials science forum*, vol. 857, pp 603-607,2016.

[45] X. Lui, R. Wang, R. Li, and B. Wang, "Multilevel Continuous Polarization Modulation with High Spectral Efficiency in the Depolarization Channels", *IEEE,* vol. 6, pp. 2169-3536, 2018.

[46] H. Sarangal, S. Singh Thapar, P. Singh, I. Sharma and H. Kaur, "Performance Estimation of Advanced Intensity Modulation Formats Using Hybrid SAC-OCDMA through IsOWC Channel", *Journal of optical communication*, vol.10, no. 1, pp. 379-386, 2018.

[47] X. Qiao, and M. A. Fiddy, "Distributed optical fiber Bragg grating sensor for simultaneous measurement of pressure and temperature in the oil and gas downhole," *Proceedings of SPIE - The International Society for Optical Engineering*, vol. 4870, 2002.

[48] K.K Upadhyay, N.K. Shukla and S. Chaudhary, "A high speed 100 Gbps MDM-SAC-OCDMA multimode transmission system for short haul communication", *Optik*, vol. *202*, pp. 163665, 2020.

[49] S. Mostafa, A. E. N. A. Mohamed, F. E. A. El-Samie, and A. N. Z. Rashed, "Cyclic Shift Code for SAC-OCDMA Using Fiber Bragg-Grating", arXiv preprint arXiv:1904.00373, 2019.

[50] K.S. Nisar, A. Djebbari, and C. Kandouci, "Development and Performance Analysis Zero Cross Correlation Code using a Type of Pascals Triangle Matrix for Spectral Amplitude Coding Optical Code Division Multiple Access Networks", *Journal of Optical communication*, vol. 159, pp. 14–20, 2018.

[51] Q. Wang, T. Song, M.-W. Wu, T. Ohtsuki, M. Gurusamy, P.-Y. Kam, "Influence of pointing errors on error probability of inter-satellite laser communications", *Opto Electronics and Communications Conference (OECC) Held Jointly with 2016 International Conference on Photonics in Switching (PS)*, pp. 1-3, 2016.

[52] M. Singh, "Modeling and performance analysis of 10 Gbps inter-satellite optical wireless communication link", *Journal of Optical Communications*, vol. *39, no.* 1, pp. 49-53, 2018.

[53] A. Koepf, R. G. Marshalek, D. L. Begley, "Space laser communications: A review of major programs in the United States.", *AEU- International Journal of Electronics and Communications*, vol.56, no. 4, pp. 232-242, 2002.

[54] U. Bhanja and S. Panda, "Comparison of Novel Coding Techniques for a Fixed Wavelength Hopping SAC-OCDMA", *Photonic Network Communications*, vol. 33, no. 2, pp. 179–193, 2017.

[55] K. Singh, M. Singh, J. Malhotra and A. Grover, "20Long-reach cost-effective 100 Gbit/s CO-OFDM-MDM-based inter-satellite optical wireless communication (IsOWC) system", *Optoelectronics and Advanced Materials-Rapid Communications*, pp. 245-253, 2021.

[56] S. Kaur, and S. Singh, "Review on Developments in All-Optical Spectral Amplitude Coding Techniques", *Optical Engineering*, vol. 57, no. 11, pp. 116-162, 2018.

[57] K. Fouli and M. Maier, "OCDMA and optical coding: Principles, applications, and challenges", *IEEE Communications Magazine*, vol.*45*, no. 8, pp.27-34, 2007.

[58] M. Singh, M and J. Malhotra, "Long-reach high-capacity hybrid MDM-OFDM-FSO transmission link under the effect of atmospheric turbulence", *Wireless Personal Communications*, vol.*107*, no. 4, pp.1549-1571, 2019.

[59] M. Singh and J. Malhotra, "Performance comparison of high-speed long-reach mode division multiplexing-based radio over free space optics transmission system using different modulation formats under the effect of atmospheric turbulence", *Optical Engineering*, vol.*58, no.*4, pp. 046112, 2019.

[60] P. Kaur, V.K.Jain and S.Kar, " Performance analysis of free space optical links using multi-input multi-output and perture averaging in presence of turbulence and various weather conditions," IET Communications, vol. 9, o. 8, pp. 1104- 1109, 2015

[61] V. Jyoti, and R. S. Kaler, "Security Enhancement of OCDMA System Against Eavesdropping using Code-Switching Scheme", *Journal of Optik,* vol. 122, no. 9, pp. 787–791, 2011.

[62] S. Benedetto and P. Poggiolini, "Theory of polarization shift keying modulation", *IEEE Transactions on communications*, vol.*40*, no. 4, pp.708-721, 1992.

[63] H. Kaushal and G. Kaddoum, "Optical communication in space: Challenges and mitigation techniques", *IEEE communications surveys & tutorials*, vol.*19*, no.1, pp.57-96, 2016.

[64] H. Sarangal, A. Singh, J. Malhotra, and S. Chaudhary, "A Cost Effective 100 Gbps hybrid MDM OCDMA FSO Transmission System under Atmospheric Turbulences", *Optical and Quantum Electronics,* vol. 49, no. 5, pp. 184, 2017.

[65] S. C. Xavier, B. E. Carolin, A. P. Kabilan, and W. Johnson, "Compact Photonic Crystal Integrated Circuit for All-Optical Logic Operation", *IET Optoelectronics,* vol. 10, no. 4, pp. 142–147, 2016.

[66] T.M. Bazan, D. Harle and I. Andonovic, "Performance analysis of 2-D time-wavelength OCDMA systems with coherent light sources: code design considerations", *Journal of lightwave technology*, vol.*24*, no.10, pp.3583-3589, 2006.

[67] T. Sharma and R. K. Maddila, "Performance Characteristics of the Spectral-Amplitude-Coding Optical CDMA System Based on One-Dimensional Optical Codes and a Multi-Array Laser", *Journal of physics,* vol. 20, no. 2, pp. 81, 2019.

[68] A. Kumar, M. Bharti, and T. Kumar, "Performance Investigation of 2-D Optical Orthogonal Codes for OCDMA", *Journal of Optical Communications*, vol. 40, no. 4, pp. 455–462, 2019.

[69] S. Kaur, and S. Singh, "A Novel Zero Cross-Correlation Diagonal Identity Matrix Code", *In2018 6th Edition of International Conference on Wireless Networks & Embedded Systems (WECON),* pp. 1–5, 2018.

[70] D. He, X. Li, S. Chan, J. Gao and M. Guizani, "Security Analysis of a Space-Based Wireless Network", *IEEE Network*, vol. 33, no. 1, pp. 36–43, 2019.

[71] R. Canetti and H. Krawczyk, "Analysis of Key-Exchange Protocols and their Use for Building Secure Channels", In International Conference on the Theory and Applications of Cryptographic Techniques, pp. 453–474, Springer, Berlin, Heidelberg,2001.

[72] P. K. Teotia, and R. S. Kaler, "1-D Grating Based SPR Biosensor for the Detection of Lung Cancer Biomarkers using Vroman Effect", *Optics Communications,* vol. 406, pp. 188–191, 2018.

[73] S. Chaudhary, A. Sharma, and N. Chaudhary, "6× 20 Gbps hybrid WDM–PI inter-satellite system under the influence of transmitting pointing errors", *Journal of Optical Communications*, vol. *37,* no. 4, pp. 375-379, 2016.

[74] S. Singh R.S. Kaler and S. Sharma, "Resonance Effect of Bimetallic Diffraction Grating on the Sensing Characteristics of Surface Plasmon Resonance Sensor with COMSOL Multiphysics", *Journal of Nanoelectronics and Optoelectronics*, vol.14, no. 5, pp. 669–674, 2019.

[75] R. Gupta, R.S. Kaler, "Performance Investigation of LP modes over MMF link to boost MIMO Mode Division Multiplexing", *Optoelectronics and advanced materials-Rapid Communications,* vol. 11, no. 11-12, pp. 643-647, 2017.

[76] R. Gupta, R.S. Kaler, "Performance Investigation of high capacity 10 Tb/s LP-MDM-WDM over multimode fiber link for short reach applications", *Optoelectronics and advanced materials- Rapid Communications*, vol. 12, no. 7- 8, pp. 441 - 446, 2018.

[77] H.A. Bakarman, S. Shaari, M. Ismail, "Security and performance tradeoffs in optical CDMA network systems", *International conference on photonics (ICP),* pp. 1–4, 2010.

[78] Y. Fazea, "Mode division multiplexing and dense WDM-PON for Fiber-to-the-Home", *Optik*, vol.*183*, pp. 994-998, 2019.

[79] S. Boukricha, K. Ghoumid, S. Mekaoui, E. Ar-Reyouchi, H. Bourouina, and R. Yahiaoui, "SAC-OCDMA system performance using narrowband Bragg filter encoders and decoders", *SN Applied Sciences*, vol.*2,* no. 6, pp.1-9, 2020.

[80] M. Moghaddasi, S. Seyedzadeh, I. Glesk, G. Lakshmi Narayana, S.B.A. Anas, "DW-ZCC

code based on SAC–OCDMA deploying multiwavelength laser source for wireless optical networks", *Opt Quant Electron.*, vol. 49, no. 12, pp.393-407, 2017.

[81] N. Marriwala, O.P. Sahu, A. Vohra, "8-QAM software defined radio-based approach for channel encoding and decoding using forward error correction", *Wireless personal communications*, vol. *72, no.* 4, pp. 2957-2969, 2013.

[82] V. Jyoti and R.S. Kaler, "Design and performance analysis of various one-dimensional codes using different data formats for OCDMA system", *Optik-Int J Light Electron Optic*, vol.122, no. 10, pp. 843-850, 2011.

[83] C. Kandouci, A. Djebbari, A. Taleb-Ahmed, "A new family of 2D-wavelength-time codes for OCDMA system with direct detection", *Optik*, vol. 135, pp. 8-15, 2017.

[84] S. Panda, "Effect of SHIFT ZCC codes for optical CDMA system", *World Sci News*, vol.2, pp. 365-389, 2017.

[85] D. Gupta, and S.K. Vishvakarma, "Improved short-channel characteristics with long data retention time in extreme short-channel flash memory devices", *IEEE Transactions on Electron Devices*, vol. *63, no.* 2, pp. 668-674, 2016.

[86] S.F. Su and R. Olshansky, "Performance of WDMA networks with baseband data packets and subcarrier multiplexed control channels", *IEEE photonics technology letters*, vol.*5*, no. 2, pp.236-239, 1993.

[87] C.C. Sueand S.Y. Kuo, "Design and analysis of accelerative pre allocation protocol for WDM star-coupled networks", *Journal of lightwave technology*, vol.*20, no.* 3, pp.338, 2002.

[88] H. Sarangal, A. Singh, J. Malhotra, and S.S. Thapar, "Performance investigation of PM-ZCC code in hybrid SAC-OCDMA system through inter-satellite OWC channel", *Wireless Personal Communications*, vol.*120, no.* 4, pp.3329-3341, 2021.

[89] A. Stok and E.H. Sargent, "The role of optical CDMA in access networks", *IEEE Communications Magazine*, vol.*40, no.* 9, pp.83-87, 2002.

[90] K.S. Gilhousen, I.M. Jacobs, R. Padovani, A.J. Viterbi, L. A. Weaver, and C.E. Wheatley, "On the capacity of a cellular CDMA system", *IEEE transactions on vehicular technology*, vol.*40*, no. 2, pp.303-312, 1991.

[91] H. Mrabet, A. Cherifi, T. Raddo, I. Dayoub, and S. Haxha, "A comparative study of asynchronous and synchronous OCDMA systems", *IEEE Systems Journal*, vol.15, no. 3, pp. 3642-3653, 2020.

[92] M. Moghaddasi, G. Mamdoohi, A.S.M. Noor, M.A. Mahdi, and S.B.A. Anas, "Development

of SAC–OCDMA in FSO with multi-wavelength laser source", *Optics Communications*, vol.*356*, pp. 282-289, 2015.

[93] J. Ji, G. Zhang, W. Li, L. Sun, K. Wang, and M. Xu, "Performance analysis of physical-layer security in an OCDMA-based wiretap channel", *Journal of Optical Communications and Networking*, vol.*9, no.*10, pp.813-818, 2017.

[94] C.H. Lin, J. Wu, H. W Tsao and C. L. Yang, "Spectral amplitude-coding optical CDMA system using Mach-Zehnder Interferometers," *Journal of Lightwave Technology*, vol.23, no.4, pp.1543-1555, 2005.

[95] S. Kumawat, and R.K. Maddila, "Development of ZCCC for multimedia service using SAC-OCDMA systems", *Optical Fiber Technology*, vol.*39*, pp. 12-20, 2017.

[96] W. Huang, M.H. Nizam, I. Andonovic, and M. Tur, "Coherent optical CDMA (OCDMA) systems used for high-capacity optical fiber networks-system description, OTDMA comparison, and OCDMA/WDMA networking", *Journal of Lightwave Technology*, vol.*18*, no. 6, pp.765, 2000.

[97] S. Kim, K. Yu, and N. Park, "A new family of space/wavelength/time spread three-dimensional optical code for OCDMA networks", *Journal of Lightwave Technology*, vol.*18*, no.4, pp. 502, 2000.

[98] H. Mrabet, I. Dayoub, R. Attia, and S. Haxha, "Performance improving of OCDMA system using 2-D optical codes with optical SIC receiver", *Journal of Lightwave technology*, vol.*27*, no. 21, pp. 4744-4753, 2009.

[99] J. Ortiz-Ubarri, O. Moreno, O., and A. Tirkel, "Three-dimensional periodic optical orthogonal code for OCDMA systems", *IEEE Information Theory Workshop*, pp. 170-174, 2011.

[100] J.E. McGeehan, S.M. Nezam, P. Saghari, T.H. Izadpanah, A.E. Willner, R. Omrani, and P.V. Kumar, "3D time-wavelength-polarization OCDMA coding for increasing the number of users in OCDMA LANs", In *Optical Fiber Communication Conference*, Optica Publishing Group, 2004.

[101] D. Bushuev and S. Arnon, "Analysis of the performance of a wireless optical multi-input to multi-output communication system," *Journal of Opt. Soc. Amer, Opt. Image*, vol. 23, no. 7, pp. 1722–1730, 2006.

[102] M.A. Anuar, S.A. Alijunid, N.M. Saad, "New design of spectral amplitude coding in OCDMA with zero cross-correlation", *Optics Communications*, vol.282, no. 14, pp. 2659–2664, 2009.

[103] V. Sharma and A. Kaur, “Modeling and simulation of FBG based OCDMA-IsOWC system”, *Optik*, vol.*125*, no. 6, pp.1727-1729, 2014.

[104] A. Amphawan, S. Chaudhary, T. Elfouly, and K. Abualsaud, “Optical mode division multiplexing for secure Ro-FSO WLANs”, *Advanced Science Letters*, vol. *21*, no.10, pp.3046-3049, 2015.

[105] G. Rademacher, and K. Petermann, “Nonlinear Gaussian Noise Model for Multimode Fibers with Space-Division Multiplexing,” *Journal of Lightwave Technology*, vol. 34, no. 9, pp. 2280-2287, 2016.

[106] C. Antonelli, A. Mecozzi, and M. Shtaif, “Nonlinear propagation in Space-Division Multiplexed fiber-optic transmission,” in IEEE Photonics Conference IPC, pp. 256-258, 2015.

[107] H. K. Gill, G. K. Walia, N. S. Grewal, “Performance Analysis of Mode Division Multiplexing IS-OWC System using Manchester, DPSK and DQPSK Modulation Techniques”, *Optik*, vol.177, pp. 93–101, 2019.

[108] F. Schmidt, and K. Petermann, “Investigation of LP- and Vector-Modes for the Analysis of Space-Division Multiplexed Systems in the Nonlinear Regime,” *Journal of Lightwave Technology,* vol. 35, no. 22, pp. 4859-4864, 2017.

[109] K. Po Ho, and J. M. Kahn, “Mode-dependent loss and gain: statistics and effect on mode-division multiplexing,” *Optics Express,* vol. 19, no. 17, pp. 16612- 16635, 2011.

[110] C.Y. Li, H.H. Lu, T.C. Lu, C.J. Wu, C.A. Chu, H.H. Lin, and M.T. Cheng, “A 100 m/320 Gbps SDM FSO link with a doublet lens scheme”, *Laser Physics Letters*, vol.*13,* no. 7, 075201, 2016.

[111] R. Gupta and R.S. Kaler, “Performance comparison of pre-boost-, and inline-multimode erbium-doped fiber amplifier configurations to boost mode-division multiplexed multimode fiber link”, *Opt Eng*, vol. 55, no. 5, pp. 056102, 2016.

[112] S. M. J. Shah, A. Nasir, and H. Ahmed, “A Survey Paper on Security Issues in Satellite Communication Network Infrastructure”, *International Journal of Engineering Research and General Science*, vol. 2, no. 6, pp. 887–900, 2014.

[113] U. Bhanja, “Design and Performance Analysis of an Encrypted Two-Dimensional Coding Technique for Optical CDMA”, In *Optical and Wireless Technologies*, pp. 573-583, 2022

[114] P.L. Bertarini, A.L. Sanches, and B.H.V. Borges, “Optimal code set selection and security issues in spectral phase-encoded time spreading (SPECTS) OCDMA systems”, *Journal of lightwave technology*, vol.*30,* no. 12, pp. 1882-1890, 2012

[115] H. Y. Ahmed, and K. S. Nisar, "Diagonal Eigen Value Unity (DEU) Code for Spectral Amplitude Coding-Optical Code Division Multiple Access", *Optical Fiber Technology,* vol. 19, no. 4, pp. 335–347, 2013.

[116] N. Ahmed, S. A. Aljunid, A. Fadil, R. B. Ahmad, and M. A. Rashid, "Performance Enhancement of OCDMA System using NAND Detection with Modified Double Weight (MDW) Code for Optical Access Network", *Optik*, vol. 124, no. 13, pp. 1402–1407, 2013.

[117] M.A. Khalighi, and M. Uysal, "Survey on free space optical communication: A communication theory perspective", *IEEE communications surveys & tutorials*, vol.*16,* no. 4, pp.2231-2258, 2014.

[118] A. Donner, "Satellite networks for aeronautical communication: traffic modeling and link load analysis", *IET Communications,* vol. 4, no.13, pp. 1594–1606, 2010.

[119] R.W. Tkach, "Scaling optical communications for the next decade and beyond," *Bell Labs Technical Journal*, vol. 14, no. 4, pp. 3-9, 2010.

[120] J. Tang, "The Shannon channel capacity of dispersion-free nonlinear optical fiber transmission", *Journal of Lightwave Technology*., vol. 19, no. 8, pp. 1104–1109, 2001.

[121] A.O. Aldhaibani, S. A. Aljunid, M.S. Anuar, A.R. Arief, and C.B.M Rashidi, "Development of OCDMA system based on Flexible Cross Correlation (FCC) code with OFDM modulation", *Optical Fiber Technology*, vol.*22*, pp. 7-12, 2015.

[122] A. Grover, A. Sheetal, and V. Dhasarathan, "Performance analysis of mode division multiplexing based free space optics system incorporating on–off keying and polarization shift keying under dynamic environmental conditions", *Wireless Networks*, vol.*26, no.* 5, pp.3439-3449, 2015.

[123] S. Panda, and G. Palai, "Design and Performance analysis of data encrypted two- dimensional coding technique for wavelength hopping time spreading Optical CDMA", *Optik*, vol.*207*, pp. 163864, 2020.

[124] M. Singh, and J. Malhotra, "A high-capacity single-channel MDM-OFDM-IsOWC transmission link with improved detection", *Wireless Personal Communications,* vol. *123, no.* 3, pp. 1987-2010, 2022.

[125] M.Z. Chowdhury, M.T. Hossan, A. Islam, Y.M. Jang, "A comparative survey of optical wireless technologies: architectures and applications", *IEEE Access,* vol. 6, pp. 9819-9840, 2018.

[126] T. Koonen, F. Gomez-Agis, F. Huijskens, K.A. Mekonnen, Z. Cao, E. Tangdiongga, "High-

capacity optical wireless communication using two-dimensional IR beam steering", *J Lightwave Technol.*, vol.36, no. 19, pp. 4486-4493, 2018.

[127] A. Al-Kinani, C.X. Wang, L. Zhou, W. Zhang, "Optical wireless communication channel measurements and models", *IEEE Commun Survey Tut*., vol. 20, no. 3, pp. 1939-1962, 2018.

[128] A. Taiwo, M. Moghaddasi, D. Kuje, Y. Idriss, M. Mokhtar, "Practical investigation of suitable decoding techniques for spectral amplitude coding optical code division multiple access-based vibration sensing", *IET Optoelectron.*, vol. 10, no. 6, pp. 227-232, 2016.

[129] S. Kumawat and M.R. Kumar, "A new code construction algorithm based on double weight codes for SAC-OCDMA systems", *In 2017 International conference on computer, Communications and Electronics (Comptelix)*, pp. 1-6, 2017.

[130] A.O. Aldhaibani, S. A. Aljunid, M.S. Anuar, A.R. Arief, and C.B.M Rashidi, "Development of OCDMA system based on Flexible Cross Correlation (FCC) code with OFDM modulation", *Optical Fiber Technology*, vol.*22*, pp. 7-12, 2015.

[131] S. Singh and S. Singh, "Performance analysis of spectrally encoded hybrid WDM-OCDMA network employing optical orthogonal modulation format against eavesdropper", *AEU-Int J Electron Commun*., vol.82, pp. 492-501, 2016.

[132] G. Ahmed, and A. Djebbari, "New technique for construction of a zero cross correlation code", *Optik*, vol.*123*, no. 15, pp. 1382-1384, 2012.

[133] K.S. Nisar, "Construction of zero cross correlation code using a type of anti-diagonal-identity-column block matrices", *Optik-Int J Light Electron Optics*, vol. 125, pp. 6586-6588, 2014.

[134] A.A. Shatnawi and M.N.B.M Warip, "High-speed and long-reach hybrid AMI–WDM–PI inter-satellite communication system", *J Opt Comm.*, vol.39, no. 1, pp. 55-59, 2017.

[135] V. Sharma and N. Kumar, "Improved analysis of 2.5 Gbps- inter-satellite link (ISL) in inter-satellite optical-wireless communication (IsOWC) system", *Optic Comm.*, vol. 286, pp. 99-102, 2013.

[136] S. Chaudhary, X. Tang, A. Sharma, B. Lin, X. Wei, and A. Parmar, "A cost-effective 100 Gbps SAC-OCDMA–PDM based inter-satellite communication link", *Optical and Quantum Electronics*, vol. 51, no. 5, pp.1-10, 2019.

[137] A. Al-Kinani, C.X. Wang, L. Zhou, W. Zhang, "Optical wireless communication channel measurements and models", *IEEE Commun Survey Tut*., vol. 20, no. 3, pp. 1939-1962, 2018.

[138] J.C. Cartledge, G.S. Burley, "The effect of laser chirping on lightwave system performance", *J Lightwave Tech*., vol. 7, no. 3, pp 568-573, 1989.

[139] V. J. Hernandez, W. Cong, J. Hu, C. Yang, N. K. Fontaine, R. P. Scott, Z. Ding, B. H. Kolner, J. P. Heritage and S.B. Yoo, “A 320 Gb/s Capacity (32 user× 10 Gb/s) SPECTS O-CDMA Network Testbed with Enhanced Spectral Efficiency through Forward Error Correction”, *Journal of Lightwave Technology,* vol. 25, no. 1, pp. 79–86, 2007.

[140] H. M. Al-Khafaji, S. A. Aljunid and H. A. Fadhil, “Improved BER Based on Intensity Noise Alleviation using Developed Detection Technique for Incoherent SAC-OCDMA Systems”, *Journal of Modern Optics*, vol. 59, no. 10, pp. 878–886, 2012.

[141] K. W. A. K. Yongjun, A. Sengupta, D. W. Lee, A. Davydov, S. Han, G. Morozov, and S. Pawar, U. S. Patent Application No. 16/127, pp. 829, 2019.

[142] S. Kaur, R.S. Kaler, and T.S. Kamal, “All-optical binary full adder using logic operations based on the nonlinear properties of a semiconductor optical amplifier”, *Journal of the Optical Society of Korea*, vol.*19, no.* 3, pp. 222-227, 2015.

[143] S. Benedetto and P.T. Poggiolini, ‘‘Multilevel polarization shift keying: Optimum receiver structure and performance evaluation*’’, IEEE Trans. Communication*., vol. 42, no. 234, pp. 1174–1186, 1994.

[144] G. Kaur, and G. Singh, “Performance analysis of SAC-OCDMA in free space optical medium using MD and DDW code”, In *2015 2nd International Conference on Recent Advances in Engineering & Computational Sciences*, pp. 1-6, 2015.

[145] F. Liu, X. Wang, R. Li, and B. Wang, “Multilevel continuous polarization modulation with high spectral efficiency in the depolarization channels”, *IEEE Access*, vol.*6*, pp.33002-33014, 2018.

[146] R.S. Kaler, T.S. Kamal, A.K. Sharma, S.K. Arya, S. K., and R. A. Agarwala, “Large signal analysis of FM-AM conversion in dispersive optical fibers for PCM systems including second order dispersion”, *Fiber & Integrated Optics*, vol.*21, no.* 3, pp.193-203, 2002.