A

DISSERTATION REPORT

on

Analysis of FSO channel using Log Normal Model and different Modulation techniques

Submitted in
partial fulfilment for the degree
of

Master of Technology in Electronics & Communication

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<u>CERTIFICATE</u>

This is to certify that the dissertation report entitled **Analysis of FSO channel using Log Normal model and different modulation techniques** composed by **Akash Gupta (2017PWC5441)**, in the partial fulfilment of the degree master of technology in **Electronics & Communication** of Malaviya National Institute of Technology, is the work completed by him under my supervision, hence approved for submission during academic session 2018-2019. The contents of this dissertation report, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

Place: Jaipur
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DECLARATION

I, **Akash Gupta**, declare that this dissertation titled, **“Analysis of FSO channel using Log Normal model and different modulation techniques”** and the work presented in it is my own. I confirm that this work is done towards the partial fulfilment of the degree of “Master of Technology” at MNIT, Jaipur. Where any part of this dissertation has previously been submitted for a degree or any other qualification at MNIT or any other institution, this has been clearly stated. I have consulted the published work of others, this is always clearly attributed, quoted from the work of others, the source is always given, with the exception of such quotations, this Dissertation is entirely my own work.

I have acknowledged all main sources of help.

Date: **Akash Gupta**

(2017PWC5441)

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ABSTRACT

Optical FSO is an economical and high bandwidth access technology that is being developed in the latest marketing implementation. This thesis analyzes the performance and methods of FSO communication to enhance the efficiency of the free optical communication link. In the field of FSO communications, a high-quality accurate information speed was researched for the ASK, Phase Shift Key { PSK }, Quadrature Amplitude Modulation { QAM } method. The method of diversity is examined and its impact on the results of FSO communication in the circumstances of atmospheric turbulence analyzed. Multi-Input-Multiple-Output { MIMO } Spatial diversity technology offers an efficient way to solve atmospheric turbulence issues including air turbulence.

This thesis presents the simulation models of the above proposed techniques using Optiwave-Optisystem tool and also presents the comparative result analysis of the betterment of the FSO link performance in terms of High Data carrying capability and reliability of the link.

KEYWORDS: Free Space Optical Communication, ASK, PSK, Channel Modeling

ABBREVIATIONS

FSO	Free Space Optics
SISO	Single-Input-Single-Output
MIMO	Multi-Input-Multi-Output
ASK	Amplitude Shift Key
PSK	Phase Shift Key
QAM	Quadrature Amplitude Modulation
DP-BPSK	Dual Polarized Binary Phase Shift Keying
CW	Continuous Wave
RF	Radio Frequency
IR	Infrared
NLOS	Non Line-of-Sight
LOS	Line-of-Sight
UV	Ultraviolet
OWC	Optical wireless communication

Symbols

mrad	Metre radian
A/W	Ampere per Watt
nA	Nano Ampere
eV	Electron Volt
dB	Decibel
µm	Micrometer
nm	Nanometer
mW	Milliwatt
cm	Centimeter
λ	Wavelength
V	Voltage
MHz	Mega Hertz
GHz	Giga Hertz
Gbps	Giga bits per second

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The most vital occurrences in the antiquity of technology is generation of "Wireless Communication". In the context of term "Wireless" used everywhere in today's technology with RF technologies for wireless RF systems/devices. The transmission of unguided propagation is from Optical wireless communication with the help of carriers' i.e. IR, UV and Visible band. The transmitter used in OWC nowadays either Laser or LED. Transporting data from one point to another, by means of optical fiber communication, using the light as carrier and optical fibres.

Free space optics, also referred to as free space photonics (FSP), refer to the transmission through the atmosphere of modulated visible or infrared rays (IR) for broadband communication. The most often used laser beams are non-laser sources such as LED or IR-emitting diodes (IREDs), although they are suitable. Over distances of several kilometres, FSO systems can operate. As long as a clear vision line is theoretically feasible between the source and destination. Even when no direct view line exists, the energy can still be reflected by strategically placed mirrors. With few or no attenuation, beams can go through glass windows.

The theory of fibre-optic transmission in FSO is fundamentally the same. The distinction is that the energy beam is collimated and transferred from the source to the location via transparent air or space, rather than driven by an optical fiber. If a sufficiently parallel beam is not produced by the energy source to travel the necessary distance, collimation with lenses can be performed. The visible or IR power at the source is modulated by transmitting data. The beam is intercepted at location with a photodetector, the information is removed (demodulated) from the visible or IR beam and the resulting signal is amplified and transmitted to the hardware.

Nowadays, the communication network is a significant factor in the core network implementation and addresses all such mainstream technologies. It is capable of tackling connectivity bottlenecks created by the enormous achievements and continuing Internet recognition in high-speed networks. While FSO technologies can be a useful answer to certain network requirements in broadband, there are constraints. The important thing is to obstruct and shut down the network with rain, dirt, snow, fog and smog.

1.1 Background

There is an increasing need for high-speed information access, each electronic infrastructure in our contemporary culture needs very high-speed information access. The only remaining high-speed data access bottleneck in our backbone networking and also in our local region network is the connecting network that connects the local area network to the backbone network. This bottleneck issue has been economically resolved by the Free Space.

The beauty of this kind of communications system is it uses a Free Spectrum License, requires no fiber installation and extension in the future. In addition to the benefits of high information rates, the FSO communications system offers the most efficient high speed wireless communication technology in the next generation, no requirement for RF licensing, high safety, a lower form factor, smallest transceiver architecture and an immunity from intrusion or jam.

1.2 Objective

The objective of our study project is to study every opportunity to improve the ability and reliability of the FSO connection through the use of all modulation and diversity techniques. In the context of spectral effectiveness and greater data rate of over 1550 nm FSO connection, QAM is used.

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Optical Free-Space (FSO) communication must be included in modern internet architecture to provide very high bandwidth. FSO communications is a most convenient solution for solving broadband bottleneck connectivity issues in today's situation and an alternative to standard radio frequency / microwave connections. FSO can be exploited in very wide-ranging scenarios using various modern technologies. In long-term and short-range apps, the data rate supplied by FSO connections continues to improve. Removing the bottlenecks of contemporary Internet-dependent culture is crucial to the future development and achievement. These ever increasing demands for higher bandwidth can be easily satisfied by the FSO technology. Figure 2.1 shows a free space communication technology method and different types of user connections with the optical wireless channel.

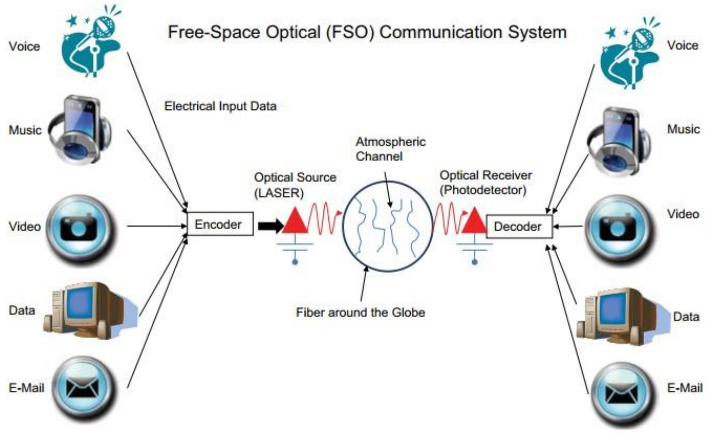

Fig. 2.1: Basic FSO Communication System [1]

The major issue with long-range FSO communication is serious scintillation due to atmospheric disturbances, which poses important beaming difficulties and results in deep link fades. The performance of FSO connections can be enhanced by interferometry, which depend on the length of the connection. The efficiency of FSO connections can also be enhanced through the use of packet-level identification sequences and FEC. Also, smart transceiver implementation and effective transmission systems can enhance connection efficiency. Non-line-of-sight (NLOS) connections using UV solar blind radiation spread from source to detector present valuable communication opportunities. Various FSO connection scenarios must meet various system requirements including distinct transmission methods, distinct propagation channel features, and reception techniques. Multiple inputs and multiple output (MIMO) techniques open different opportunities for FSO connections under different environmental circumstances (disturbance and dispersion). MIMO deployment in FSO scenario can drastically mitigate the atmospheric perturbations by exploiting the benefits of spatial diversity techniques and can improve its link performance.

2.1 FSO Connectivity in Todays Networks

Free Space Optics is a LOS technology that transmits amplified beams of light, to the environment for the establishment of optical communications. In some scenarios, FSO can also use NLOS tech with dispersion to identify the optical beam modulated for the data transfer within the coverage area. There is many benefits to FSO communications: the most important thing is that it works in non-licensed Tera-Hertz frequency bands that enhance carrier bandwidth across RF, is safe with small intrusion likelihood, FSO transmissions are susceptible to EMI)etc. FSO systems have several additional benefits including simple installation, reduced cost per bit and application independent of various platforms and interfaces. Because of these benefits, FSO was regarded as among the most viable techniques for broadband channels of the next decade. The main drawback of FSO is that of the climate. If the communication connection contains portion of the environment, no turbulence and a possible border turbulence (e.g. an apex of transmission connection on an aircraft), severe phase deflections will occur and the connection will fade away. The connecting failures and poor reliability caused by atmospheric perturbations can also affect FSO channels. Weather conditions like mist, fumes, precipitation, rain, tiny particles etc. influence the efficiency of FSO transmissions. For FSO transmission of 1 Gbps, the 100 milli seconds flash delay is 108 frames (i.e. 12.5 Mbps), which causes significant data loss if the wave at the receiver interacts with the flash [2]. Solar radiation distortion also affects the FSO connection, so that when a solar radiation drops on the phototransistor receiver they have to be regarded for connecting efficiency.

2.2 Optical Networks

FSO system offers its most versatile networking alternative for maximum wireless capacity. FSO technique offers the vital characteristics needed to take traffic to the fiber optic backbone with virtually limitless capacity, low price, convenience and deployment velocity. In FSO channel communication, data can be distributed via an encoded link providing the level of protection needed for particular reliable applications.

2.2.1 FSO Architectures

There are three primary fundamental FSO architectures.

- Point-to-point: This is indeed a specialized architecture link that offers better network capacity but less scalable.
- Mesh: It provides redundancy and greater efficiency with simple scalability, i.e. simple addition of nodes, but with restricted distances.
- Point-to-multipoint: This provides financial links and simple node extension, but at a reduced capacity expense than point-to-point alternative.

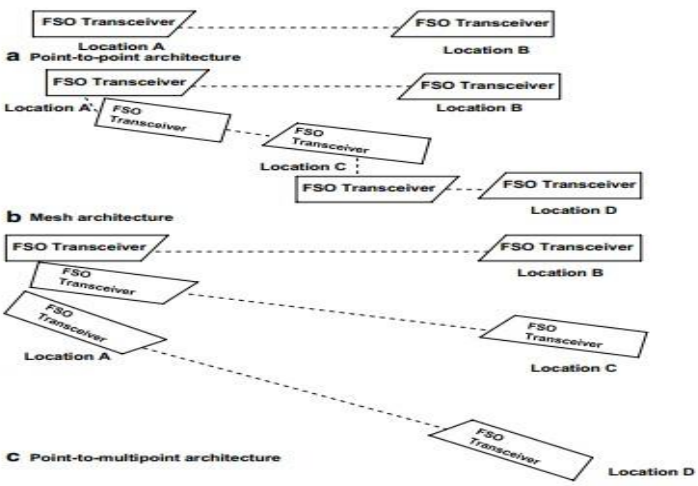

Fig. 2.2: Three Main Architectures of LOS-FSO Communication [1]

Figure 2.2 demonstrates the three primary LOS-FSO-link architectures for the establishment of a duplex-full communication. All such FSO transceivers are linked by wires to digital routers in building blocks and linked to a government or private grid channel.

2.2.2 FSO Network Implementation [1]

The implementation of the FSOC network is based on Figure 2.3.The Network access composed of a Base Station (BS), linked to the Backbone fiber ring system. The Base Service (BS) is used for the execution of the FSOC network. A range of optical transceivers is provided for each base station which acts as a temporary entry point or a point of reference to another connected structure.

The system architecture eliminates the one-point-of-failure fault between one stage and multi stage. The CPE Nodes of the client premises can be fibre-connected to the Channel Termination Units (NTU). The CPE nodes can be shared by different devices / subscribers in the underlying network. The key network includes:

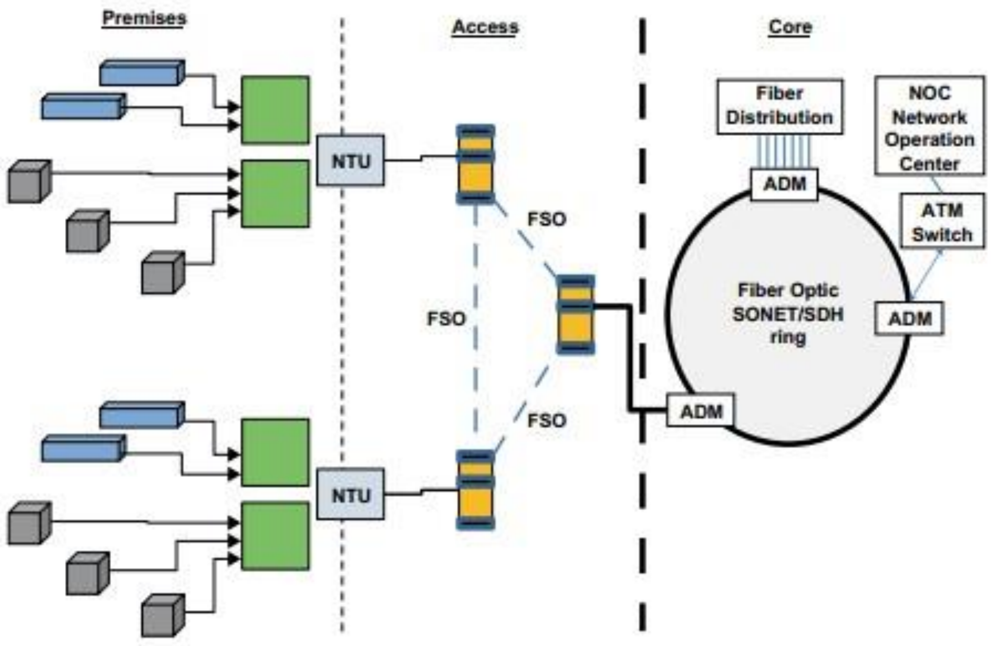

Fig. 2.3: FSO Network Implementation [1]

1. Asynchronous transfer mode (ATM) switch
2. SONET / SDH optical fiber ring serving as a core.
3. Add-drop multiplexers (ADM)
4. Network operation center(NOC) infrastructure

NOC utilizes Network Management Software (NMS) to manage and monitor data quality activities. The ADM enables to multiplex and de-multiplex information at different network interfaces. The ATM switch controls and adjusts information.

3.1 Literature Review

Mohammad Ali Khalighi et al. [4] in their survey, concentrating on terrestrial outdoor OWC connection in the vicinity of IR band. These are commonly referred to in literature as free space (FSO) interaction. They addressed FSO Systems that are employed for high-rate communication over distances of up to several miles between two fixed points. They said that FSO connections have very elevated optical bandwidth, enabling much better information rates, compared to counterparts for the radio frequency (RF).

Bach T. Vu et al. [5] theoretically analyzed Free-space optical (FSO) system output with rectangular QAM modulation and a photodiode avalanche (APD) receptor via atmospheric turbulence channels performance of the FSO. In an assessment for instances of weak / moderate and heavy atmospheric turbulence, log-normal and gamma-gamma channel models were used. The error rate for the Gray Code is obtained in theory by taking account of a variety of interconnection circumstances and system parameters, including APD shot noise, heat noise, channel attenuation and geometric loss, air turbulence strengths and connection distances.

Goran T. Djordjevic al. [7] presented Analysis of the precise average free space optical system bit Error Rate (BER) using SIM with Gray Coded QAM. The intensity changes induced by path loss and atmospheric turbulence and pointing mistakes were calculated in the received optical signal. The precise closed form analytic terms for the average BER have been obtained assuming that the Gamma-Gamma scintillation has arbitrary constellation sizes in the SIM-QAM. There have also been simple, approximate average BER expressions given only the dominant term in finite sums of the expressions obtained. The derived terms have been decreased into the particular situation if only atmospheric turbulence affects optical signal transmission. Numerical findings were provided to show that the derived expressions were useful, as well as to provide insight into the impacts on the average BER performance of various modulations, channel and receiver parameters.

Tawfik Ismail et al. [3] presented the idea of Free space optic and mmWave communications, introduced the technologies, its related challenges and the wide range of its applications. How FSO can support the demands of high band- width requirement of future network is discussed in detail

Arun K. Majumdar [1] the notion of FSO theoretically along with the system strategy was discussed widely in his book. The book offers the fundamental material of a thorough introduction to the FSO Communications principles and apps, which are extremely helpful as regards the FSO in studies.

Laith Kadhim et al. [6] presented the novel of 1.12 Tbps DWDM for a coherent 16-level QAM. The system is configured in a line-of-sight and uses a consistent 16QAM optical technique. The system has 4 channels, 280-Gbit / channel bit rate and adjacent 200GHz distance from the channel. For 16/64 QAM and single / double polarisation, the system was analyzed.

William G. Cowley et al. [8] The 2 Mbit / s FSO and codec transceiver designed to provide secure communication on a 12 km optical channel, including a sufficiently big interleaver and a powerful channel code coding system with low-density parity control (LDPC) code, plus synchronisation algorithm.

Jaspreet Kaur et al. [9] the M-ary QAM FSO under modulation connects over AWGN channels performance analysis was provided. The performance of FSO links over adverse atmospheric conditions using Mary-QAM (Quadrature amplitude modulation) schemes has been experimentally studied. Their analysis revealed that for increasing values of M, the data rates improved considerably at cost of degraded bit error rate performance. Therefore, trade-off must be maintained between acceptable system error performance and required data rate.

Harjeevan Singh et al. [10] presented the notion of Bit Error Rate Comparison of distinct Modulation Techniques over FSO Link. They have been researched in turbulent circumstances using Gamma Gamma wave model in contrast to modulating methods such as M-ary Qam, BPSK and DPSK. During this connection assessment it was noted that BPSK performed far better with regard to BER for comparable SNR values compared with

DPSK and M-ary QAM and, more interesting, the degradation of connection quality was noted, more in the order of M-QAM and more in connection with the linkage spectrum.

Mohamed B. El-Mashade et al. [11] The MIMO-FSO connection was drawn up and its performance analysed in harsh circumstances. In the case of atmospheric attenuation, achieveable improvements in performances including power levels, bit error rate (BER) and Q- factor were shown. The findings for SISO and MIMO schemes with items ranging between 2 and 4 were provided.

Mohammad Taghi Dabiri et al. [12] used an M-transceiver spatial multiplexing system to improve the data rate for the FSO. Each transmitter sends autonomous data to the middle of its associated recipient aperture in its suggested system. The results of the suggested system were evaluated in relation to the average rate achievable. They have described a situation in which M transmitters transmit the same data to counter the efficiency of their suggested scheme with their spatially diverse FSO systems. They also obtain analytical terms for the spectral efficient spatial multiplexing and variety settings in order to enhance performance analyses.

Dr. Shehab A. Kadhim et al. [13] simulated and analyzed the performance of MIMO configurations under clear, haze and fog conditions and compared the results with single input/single output SISO technique, They indicated that the MIMO receives numerous autonomous copies at the recipient of a single signal, leading in an enhanced SNR and BER.

Manav R. Bhatnagar et al. [14] presented a GG Fading FSO MIMO Links performance including Pointing Errors. PE, caused by the construction path, can eradicate the advantages of the FSO communication scheme based on apertures. Therefore the impact of PE's in GG, a fading atmospheric fluctuation, is regarded for FSO MIMO scheme. Two plans for MIMO FSO systems have been revealed: 1) EGC, and 2) MRC. They have suggested a fresh representation based on power series for the GG Fading FSO Probability Function with PEs.

Anshul Jaiswal et al. [15] The performance survey and the diversity of FSO-MIMO by OSSK was revealed. The combined effects of AT and PE's have been studied in the Bit

Errors (BER) and Channel Capacity in a Multifunctional Input system MIMO using OSSK.

Isaac I. Kim et al. [16] presented a wireless communication via optical at 785 nm and 1550 nm through laser beam. They have model to analyze atmospheric attenuation when different type of scattering particulates are present in atmosphere.

K. Prabu et al. [17] BER analysis having great turbulence with PE's for BPSK-SIM using different FSO's like SISO and MIMO. They analysed BER and output performance in strong AT with a BPSK SIM, for both SISO and MIMO FSO's.

Ningbo Zhao et al. [18] submitted a significant survey of space-multiplexed communication capability boundaries. Orbital angular momentum was suggested as a fresh manner of multiplexing to attain ability outside the traditional methods of multiplexing.

3.2 Various Application of FSO

1. Backhaul: It can be useful when transporting mobile phone traffic with high velocity and high information rate back to the PSTN from antenna towers. The transmission rate would rise [20].

2. Storage Area Network (SAN): For the forming of a SAN, FSO connections may be used. It is a network that offers access to centralized information storage at block level [19].

3. Last-mile access: The cost of drilling to laying fiber in the finish kilometer is large and it would be useful to lay as many fiber as necessary for delivery suppliers. The last kilometre, together with other networks, FSO can be used to fix such a issue. It's a fast connection. It is useful to circumvent local loops of various networks [20].

4. Outdoor wireless access: Wireless service suppliers may use the wireless service provider for communication and no FSO permit as needed for microwave bands is needed.

5. Fibre backup: FSO's are used to provide a backup connection if the transmission via the fiber is not successful. [20].

6. Metro-network extensions: The fiber rings of an current metropolitan region can be extended. The FSO scheme is used in less time, and it is easy to link fresh networks and key infra structure. It is also suitable for completion of SONET rings [20].

7. Military access: As this is a safe and imperceptible system, it can securely connect larger regions with negligible planning and usage time [23].

8. Enterprise connectivity: It’s easy to install FSO systems. Such characteristics allow the connection of two structures or another property to interconnect LAN sectors [20].

9. Service acceleration: It offers clients immediate service when their fiber equipment is implemented meanwhile. [20].

10. Bridging WAN Access: FSO promotes WAN, where it supports phone users and small satellites with high velocity information facilities and serves as a foundation for heavy-speed ethernet networks [21].

11. It is used to interact from point to point, two buildings, two ships, and point-to-multipoint links, for example, from aircraft to ground or satellite to ground, for short and long reach communication [22].

Theory of propagation through atmospheric Channel for FSO communication signal — Chapter 4

4.1 Introduction

Optical communication depends on the spread of optical radiation through air media, so the relationship of optical radiation with this medium must be studied. In the creation of efficient, price-effective and reliable FSO connectivity links, the understanding of environmental occurrence and how they influence the optical beam transmission is crucial. In the last decade, FSO communication has drawn growing exposure for several apps that provide wireless connections with high bandwidth.

Some of these apps include inter-links satellite to satellite, up-and-down connections between space systems and planes, boats and others on the floor, and between the portable or static stations for air resolution to the final mile issue. There are a number of difficult characteristics of the air channel which can lead to severe signal decay and even to total signal loss.

The environment is comprised of gaseous molecules, water vapours, spray aerosols, powder and contaminants of wavelength similar to that of a typical optical carrier which is unusual for radio frequency (RF) transmission of the carrier wave. Accumulation and dispersal due to the pollutants can considerably alleviate the optical signal being transferred, while the wave front performance of the signal-bearing atmospheric laser beam can be considerably reduced, causing a decline in intensity, enhanced bit rates and unwanted signal losses on the receiver. Discrete irradiation variation of the laser light obtained by AT generally relates to an ionization impact. Therefore, the environment could be a critical factor in accurate FSO optical connection efficiency with a large-data rate. It is thus crucial to know about both the contact between optical wave and environment, so that in the existence of the atmospheric means of communication, the FSO communication efficiency can be predicted.

4.2 Atmospheric effect on FSO Propagation

For FSO, the majority of its characteristics are influenced if an optical beam spreads through the environment. The environment is a combination of air, molecules and particulate matter that continually gains or loses thermal energy. The motion of air particles causing heat disturbance in air cells is continuous and the index, thickness and stability of air refractive changes are inhomogeneous and diverse. The environment, including modifications on polarization refraction, absorption and dispersion, and attenuation, is thus significantly impacted by most characteristics of the FSO laser beam. The beams of light at frequencies from 10 MHz and 200 MHz [24] or higher result in random changes. When the beam interferes with AT, its polarization and coherence vary because of random variations in air mass along it's route and attenuation changes consistently as a result of uncoherent loss of energy across the air weight. Due to changes in time and space irradiation of the beam of light, from either the broadcasting point of perspective, when the signal reaches the recipient, its intensity varies. Moreover, the signal frequently concentrates on and defocuses the photodetector. The variability of signal caused by AT is called scintillation. The laser light emission spectra is a significant impediment to gigabit and optical transmissions at a lengthy range [25,26]. In FSO interaction connections, scintillation understanding is essential to deterrent system efficiency (evaluated by scintillation ratio). The acoustic channel has a range of harmful properties which can result in a severe signal shrinking and even a total signal destruction. The detérioration of signal obtained does not only impact AT. In the existence of dispersed forms of media such as mist, aerosol, thick smoke etc, the FSO interaction link must be developed in several circumstances. Absorption and dispersion by pollutants can decreasing the transferred optical signal considerably in the environment, meanwhile discrete distortions of the environment caused by optical disturbance could considerably deteriorate the wave-front performance of a signal-carrying projectile causing a decreased intensity and random signal loss in the receiver [26, 27].

4.3 Different Scenarios for FSO Communication

FSO is primarily an outside connectivity technology with much more than 120 Gbps capacity to support information rates. However, there can be variety of scenarios where FSO can be implemented, few of them are mentioned here:

- Horizontal Link: Thus, some FSO devices on high wires can be attached, either from rooftop of skyscrapers, from window to rooftop, from window to window. Some FSO connections can include a Transceiver, Network infrastructure, and cellular stations. Typically the distance between the flat connection and residential areas in metro zone is up to a few blocks. The magnitude of the turbulence is generally considered constant for the horizontal link in the calculation of the variable intensity of the obtained signal. The laser field of vision can be momentarily or constantly blocked by physical obstacles such as animals, insects, plants, limb or other influences. In addition, air movement, variable heating or cooling, construction or ground movement over period can lead to severe malalignment of the FSO Fixed Site Communications System.

- Slant Path FSO Link: If the route isn't quite flat and the distortion power is not consistent along route of transmission is variable, the slow trajectory situations may occur. In addition, unmanufactured air vehicles (UAV or airborne) or the top of a cliff on the floor as shown in fig 4.1b are instances of the other sections of the novel.

- Uplink: A classic instance is the ground-to-space transmission route for the uplink situation, like a satellite base station. In order to calculate the variations in signal severity receivable at receptor as shown in fig 4.1c, the elevation profile of the turbulence resistance constraints must be considered.

- Downlink: A downlinking FSO interaction, as a remote-to-ground connection, is an instance from room to room. To calculate obtained FSO signal intensity variations as shown in fig 4.1d, the height change in the turbulence toughness must be regarded.

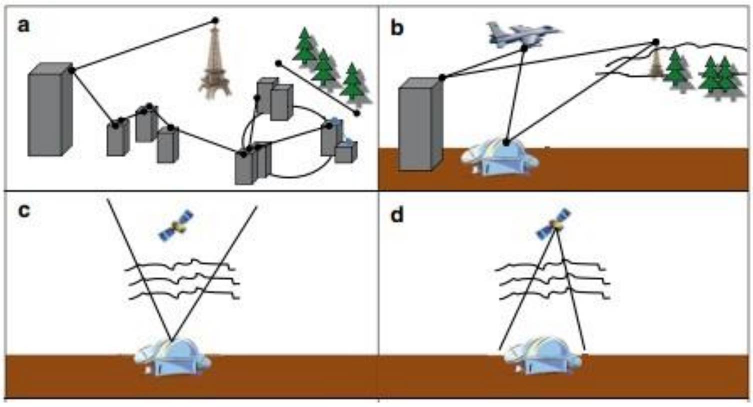

Fig. 4.1: Various Scenarios for FSO Communication :(a)Horizontal Link (b)Slant Path FSO Link (c) Uplink (d) Downlink [1]

4.4 Theory of Propagation of Optical Energy through Turbulent Atmospheric Channel for FSO

For Wireless Optical communication links, due to a variety of impacts, environmental disturbance can trigger changes in signal levels obtained that enhance bit errors in a digital communication connection. A deeper knowledge of these impacts is necessary to evaluate the FSO efficiency limits. Known air disturbance impacts include:

(A) Beam spread: Increased differences in the beam owing to dispersion, which reduces the power density obtained.

(B) Beam steering: Angular beam variation from the initial sight line (LOS) causes the receiver to miss the beam.

(C) Image dancing: The concentration on the beam moves into the plane one owing to differences in the AOA; the AOA wave-front fluctuates on the recipient.

(D) Beam scintillation: Disruptions in the recipient plane's spatial power output. Compared to high information rates for classic FSO propagation, the scintillation method is small.

(E) Spatial coherence degradation: Turbulence often causes coherence losses around the beam wave-fronts may be harmful for incoherent receivers for image blending.

(F) Other degradation involve (i) beam profile variances from the moment dependent (ii) beam center (iii) in the lighting spots whose structure and position varies with the moment.

Theoretically, the wave equation of electric field and its corresponding quantitative moments can be solved by discrete differences in the amplitude and phases of the propagation wave. The wave equation deriveed from the electrical field for the perpetuating wave:

$$\nabla E + k\ n\ (r)E + 2\nabla[E.\nabla\log n(r)] = 0 \qquad (4.1)$$

Where, k = 2π/λ is EM wave wave-number, λ is the wavelength, n(r) is time variative refractive index.

There are adequate time differences throughout the refractive index so that an almost stable method is used where n(r) is just a position component. The third word on the left hand of 4.1 is a terminal of depolarisation and may be ignored in order to write 4.1 as:

$$\nabla E + K .n. E = 0 \qquad (4.2)$$

The latter vector E equation can be broken down into three scalar models, one of which is marked by a scalar element U(r). This scalar element U(r) is cross-sectional across the positive Z axis in the path of transmission. The scalar Helmholtz stochastic formula can be formulated in the following words:

$$\nabla U + k\, n(r)\, U = 0 \qquad (4.3)$$

To resolve the 4.3 on here for soft turbulence, was used. Rytov's approximation, which enables the EM wave field to be written as:

$$U(r, L) = U_o (r, L) \exp [\varphi(r, L)] \qquad (4.4)$$

Where Uo(r) is the unimpaired field, i.e. the optical wave that traverses the receptor fr ee space, ϕ is a complicated turbulence-related disruption phase, and it can be formulated as:

$$\phi(r, L) = \phi_1(r, L) + \phi_2(r, L) + \ldots \qquad (4.5)$$

Scintillation Index: The eventual limitation of FSO interaction efficiency can be atmospheric turbulence. Thus, when large-bandwidth information are transmitted via AT, the scintillation coefficient is supportive in deterging the efficiency of the communication scheme. Andrews and Phillips, 2005[28] have taken full advantage and developed the numerical formulas in this chapter. The coherence cross function of order four is:

$$\Gamma_4(r_1, r_2, r_3, r_4, L) = U_o(r_1, L)U^*_o(r_2, L)U^*_o(r_3, L)U^*_o(r_4, L)$$
$$`\exp[\phi(r_1, L) + \phi^*(r_2, L) + \phi(r_3, L) + \phi^*(r_4, L)]e \quad (4.6)$$

4.5 Modulation Techniques

As today the Main problem in the FSO communication is Attenuation caused by atmospheric turbulence like Smog, fog etc. To decrease the BER we have used different modulation methods which can be implemented practically. We can see a significant reduction in the bit error rate with these modulation schemes.

4.5.1 Phase Shift Keying (PSK):

Let we are transmitting the digital data. In PSK we lump bits together so that in this N-bit symbol, extending over the time period NT_b, there are $2^N = M$ possible symbols. Now let us represent the symbols by sinusoid of duration $NT_b = T_s$ which differ from one another by the phase $2\pi/M$.

Phase-shift keying (PSK) is a one of the famous and very commonly used digital modulation process which processes the data by modulation of phase of a carrier signal where carrier signal is marked as reference signal. Changing the phase of sine or cosine input waves at some precise times results to phase modulation. PSK is widely used for different wireless channels such as LANs, RFIDs and Bluetooth communication devices.

Every digital modulation scheme such as ASK, PSK, FSK uses some finite number of distinct signals for representation of digital data. PSK scheme uses a finite number of phases where each phase is provided with a unique binary digit pattern. Generally, every phase encodes an equal amounts of bits. Each binary bit pattern creates a symbol which is represented as a particular phase. The demodulator, specially de-signed for the symbol-set used by phase modulator, helps in determining the phase of back to the symbol it represents, thus recovering the received signal and maps actual data. This allows the receiver to compare the phase of the received signal to that of the reference signal, such type of system is named as coherent or referred as CPSK. As an alternate, despite of operating with a constant reference wave, the broad- cast can even operate with respect to itself. Changing in phase of a single-broadcast waveform can be considered as significant items. In such systems, the demodulator determines the changes in the phase of the received signal instead of phase of reference carrier wave. As the above scheme is based on the difference between successive phases, the scheme is termed as differential phase-shift keying (DPSK). DPSK can be more simple then implementing an ordinary non coherent PSK scheme, i.e. there will be no need of having a copy reference carrier wave for the demodulator to determine the exact same phase of the received signal, with a disadvantage of having a trade-off of more demodulation errors.

In PSK scheme, the chosen constellation points are generally positioned around a circle with equal angular spacing between two successive points. This provides the maximum phase-separation between two successive points on the circle to reduce the at most chances of corruption. All the points are positioned on circle which provides one an extra edge of transmitting the bits with the same energy level. Using the same, representation of complex number modulation is going to be the same for amplitude of sine and cosine waves. In this concern, two best examples are BPSK and QPSK. Where BPSK scheme uses two different phases for modulation and QPSK uses four different phases modulation. Even though any number of phases can be used but BPSK and QPSK are simple and yet effective. Since the data being transmitted is binary in most of the cases, thus PSK scheme is generally designed with cancellation points of power of two.

BPSK also called as PRK (Phase Reversal Keying) or 2 PSK is the simplest form of phase shift keying (PSK). The scheme uses two phases where both phases are separated by a phase angle of 180 degree as the name suggests 2-PSK. In the above scheme the positioning of constellation points does not matter because still it can only modulate up to 1 bit/symbol and thus is not that much suitable for high rate data transmission applications.

4.5.2 Quadrature Amplitude Modulation (QAM):

Quadrature amplitude modulation (QAM) is dual scheme uses both an analog and a digital modulation techniques. It helps transmitting two analog message signals or two digital bit streams, where both the analog or digital information is modulated using ASK or digital modulation scheme or AM modulation by modulation the amplitudes for both carrier waves. For ASK both carrier waves having the same frequency components which are out of phase by 90 degree with each other and thus termed as quadrature carriers which makes the name of the scheme as Quadrature Amplitude Modulation. Once the carrier signals are modulated they are added to each other to for a waveform as a combination of both PSK and ASK schemes, in the analog signal modulation, generated waveform is a combination of phase modulation (PM) as well as amplitude modulation (AM). In the digital QAM technique minimum of two phases as well as two amplitudes are used for modulation. Most of the PSK modulators are designed on QAM principle. But the designed PSK modulators are not QAM because the modulated carrier amplitude based on QAM uses an 802.11 Wi-Fi standards. More over a high spectral efficiency is achievable with QAM by selecting proper constellation size and proper selection of other parameters.

QAM also transmits the data by making some modification to the actual carrier signal. In QAM technique, the amplitude of two reference waves are amplitude modulated where both the signals are having the same frequency components where both the frequency components are 90 degree out-of-phase to each other. Such idea of Amplitude modulation two carriers in quadrature to each other, results for modulated carriers are both in amplitude as phase modulated. Phase modulation and PSK is a special case of QAM technique, where the magnitude of the modulating signal in QAM is kept constant while the phase of QAM is changing.

DIGITAL QAM

Other modulation schemes, the constellation diagram is also useful for QAM. In QAM scheme, the constellation points are generally places a square grid of equal vertical and horizontal spacing, even though other possible configurations such as Cross QAM are also there. Since QAM is square grid, there are a rare possible common forms are present, most commonly used forms are 16-QAM, 64-QAM and 256-QAM. Moving toward a high-order constellation diagram, there is a possibility to transmit more bits per symbol. Whatever be the case is the mean energy of the constellation should remain unchanged, to do so the points positioned in the QAM must be closer to each other which can be more susceptible to noise and other possibilities of corruption. This results in a high bit error rate and thus higher order QAM is able to deliver more amount of data but less reliably to lower-order QAMs, for a constant mean constellation energy. Uses of higher-order QAM with no increment to bit error rate does requires a high signal-to-noise ratio (SNR) by increasing the signal energy as well as reducing noise, or performing both at the same time. Data rates higher than the those offered by 8-PSK are required, it is more usual to move to QAM since it can achieve a high gap between successive points in the I-Q plane if the planes are distributed evenly. The biggest disadvantage for above scheme is that performing the above will result in a change in amplitude of constellation so the detector may not be able to detect the phase and amplitude with perfection.

4.5.3 MIMO Technique

Multiple Input Multiple-Output (MIMO) is a wireless system that utilizes various transmitter and sensors to communicate more data simultaneously, when MIMO technique utilizes a electromagnetic waves concept called multipath, in which transmission data tumbles off walls, ceilings as well as other items in several ways and significantly differs from getting the signal. It helps antennas function more efficient by allowing them to mix data flows coming from distinct routes and to efficiently boost the capacity of receiver signal collection in a distinct way. Smart arrays use spatial diversity technique, which brings excess antennas to excellent use. The MIMO WLAN technology allowed to significantly boost a channel's ability with the help of various antennas. With each pair of reflectors added to the system, the number of receiving and transmitting antennas can be increased linearly. That's one of the most significant wireless methods used in latest years by MIMO wireless communication.

MIMO is a radio antenna method, because it utilizes numerous antennas on the source and the destination to communicate the information through various signal routes. One of the key concepts behind the space-time signal processing of MIMO wireless devices is time complemented by temporal dimension inherent to numerous spatially spread antennas, i.e. the utilization of various antennas at separate locations.

Consequently, MIMO wireless devices can be considered a logical development of the intelligent antennas used to enhance the wireless network for several years. The amount of accessible routes is the direct path between source and destination. Earlier, these several routes were used only to interfere.

5.1 Optiwave Systems

Optiwave is a leading provider in the areas of adaptively expanding photonics nanotechnologies, microelectronics and other apps, developing advanced software instruments for component layout, forming & optimization.

Optisystem version 16 software have many components which is described as below:

[1] Pseudo Random Generator:

An algorithm for generating a number sequence with peculiarities approximate to the characteristical sequences of random numbers is a pseudorandom number generator (PRG). The pattern produced by PRNG is also not random, because the original seed (which can actually contain random values) is defined by its original value. Even though sequences nearer to them can be produced using the hardware random number generator, pseudo-allocation number generators are essential for their speed and reproductivity in practice. Cryptographic apps require that output from previous inputs is not consistent. More advanced algorithms that do not possess an easy PRNG linearity are necessary.

Periodicity:

A PRNG can be initiated with a seed state from an arbitrary original state. When inputted with this state, it'll always generate that same sequence. The PRNG period is therefore described: the maximum length for repetition-free prefix of the series, over all starting states. The time period is related to the number of iterations, typically in bits. The duration of the interval may double after every "state" added, it is easy to construct PRNGs with intervals long enough even for several real world applications.

If a PRNG's internal state contains n bits, its period can be no longer than 2" results and may be much shorter. For some PRNGs, the period length can be calculated with- out walking through the whole period. Linear Feedback Shift Registers (LFSRs) are usually chosen to have periods of exactly 2^n -1. Linear congruential generators have periods that can be calculated by factoring.

[2] Line Coder:

In telecommunication, a line code is a code chosen for use within a communications system for transmitting a digital signal down a transmission line. Line coding is often used for digital data transport. Some line codes are digital base band modulation or digital baseband transmission methods, and these are baseband line les that are used when the line can carry DC components Line coding consists of representing the digital signal to be transported, by a waveform that is appropriate for the specific properties of the physical channel (and of the receiving equipment). The pattern of voltage, current or photons used to represent the digital data on a transmission link is called line encoding. The common types line encoding are unipolar, polar, bipolar, and Manchester encoding. We use a unipolar Non return to Zero Encoding for digital transmission.

[3] Mach Zender Modulator:

A Mach Zender modulator is used for controlling the amplitude of an optical wave. The input waveguide is split up into two waveguide interferometer ans. If a voltage is applied across one of the arms, a phase shift is induced for the wave passing through that arm. When the two arms are recombined, the phase difference between the two waves is converted to an amplitude modulation. This is a multi-physics model, showing how to combine the Electromagnetic Waves, Beam Envelopes interface with the Electrostatics interface to describe a realistic waveguide device.

[4]Oscilloscope:

An oscilloscope is a laboratory instrument commonly used to display and analyse the waveform of electronic signals. In effect, the device draws a graph of the instantaneous signal voltage as a function of time. A typical oscilloscope can display alternating current (AC) or pulsating direct current (DC) waveforms having a frequency as low as approximately 1 hertz (Hz) or as high as several megahertz (MHz). High- end oscilloscopes can display signals laving frequencies up to several hundred gigahertz (GHz). The display is broken up into so-called horizontal divisions and vertical divisions. Time is displayed from left to right on the horizontal scale. Instantaneous voltage appears on the vertical scale, from left to right on the horizontal scale. Instantaneous voltage appears on the vertical scale, with positive values going upward and negative values going downward.

These days, typical high-end oscilloscopes are digital devices. They connect to personal computers and use their displays. Although these machines no longer employ scanning electron beams to generate images of waveforms in the manner of the old cathode-ray "scope" the basic principle is the same. Software controls the sweep rate, vertical deflection, and a host of other features which can include: Storage of waveforms for future reference and comparison, Display of several waveforms simultaneously, Spectral analysis, Portability, Battery power option, Usability with all popular operating platforms, Zoom-in and zoom-out, Multi-color displays.

[5] PIN Photo-Detector

An optical detector is a device that converts light signals into electrical signals, which can then be amplified and processed. The photodetector is as essential an element of any fibre optic system as the optical fibre or the light source. Photodetectors can dictate the performance of a fibre optic communication link. Semiconductor photodiodes are the most commonly used detectors in optical fibre systems since they provide good performance, being small in size, and are of low cost its intensity Sensitivity measures the response to an optical input signal as a function Photodetectors sensitivity can be measured in two concepts: quantum efficiency and responsivity.

[6] CW Laser Source:

A CW laser is a laser that emits a continuous laser beam with a controlled heat output as beam duration and intensity. CW lasers are focused more around power and high output, so you will most commonly see CW lasers being used in industrial settings Some of the industries that you will most often find it being used in an automotive, aerospace, electronics and semiconductor industries, as well as the medical sector. CW Lasers are most often used to work with metals, but ate also used to work with some type of ceramics too. Metals can include steel, copper, titanium, nickel, brass and reflective metals such as silver, gold and aluminium. Its a particular benefit that our CW fibre Lasers can work with reflective metals as other types of laser, such as gas lasers, struggle more due to the reflective nature of the metal. The biggest benefit of using a CW laser is the fact that it emits one, constant beam.

6.1 MATLAB Channel Model

Log Normal Channel: The popular statistics used to classify ambient disturbance channels are indeed the lognormal, K-negative, and Gamma-Gamma models. The lognormal propagation describes small disturbances and can describe FSO transmissions over many hundred meters in cloudless connections. The K-distribution is appropriate for explaining powerful disturbances over many kilometer-long connections. The negative exponential distribution of saturated scintillation defines the constraint scenario. The Gamma-Gamma distribution is a broad variety of turbulence models which can be used. In this study, the emphasis is placed on a lognormal disturbance channel, but still the recognition algorithm created is generalized enough and can be implemented to any mathematical model.

The optical irradiance I is provided for the lognormal channel system:

$$I = e^{X} \tag{6.1}$$

The parameter σ is known as scintillation intensity. Turbulence quality impacts are minimized when the scintillation concentration is below 0.1, thus a scintillation concentration of 0.1 to 0.5 can be described by a SNR optimized detection scheme. This is the standard scintillation interval.

$$p(I) = \frac{1}{\sqrt{2\pi\sigma_l^2}} \frac{1}{I} \exp\left\{-\frac{\left(ln\left(\frac{I}{I_O}\right)-E[l]\right)^2}{2\sigma_l^2}\right\} \qquad I \geq 0 \tag{6.2}$$

6.2 Log Normal Model with FSO

Firstly, Log Normal Model is simulated with the help of FSO channel. Here we are considering scintillation σ = 0.1 for weak turbulences and mean μ= 0.The Structure for the Log Normal Model with the help of OPTIWAVE System is shown below:

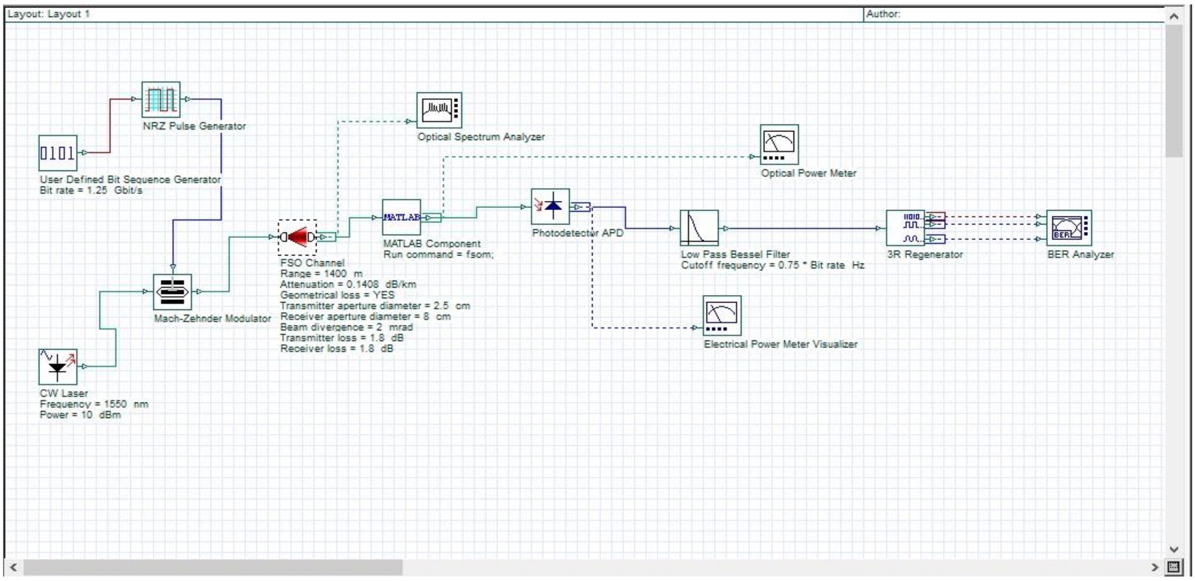

Fig 6.1 Log Normal Model with FSO

Parameter	Value
FSO Channel Range	1400 m
Channel Wavelength	1550 nm
Attenuation	0.1408 dB/km
Power	10 dBm
Bit rate	1.25 Gbps
Current	10 nA
Responsivity of PIN	1 A/W
Transmitter diameter	5 cm
Receiver Diameter	20 cm
Divergence	2 mrad

Tab. 6.1: Parameters for FSO log-normal Simulation.

The BER analyzer shows Q-factor which has to be minimal value of 6 for good communication. Below output of BER analyzer are shown through which we can consider Log Normal model is good upto 1 km.

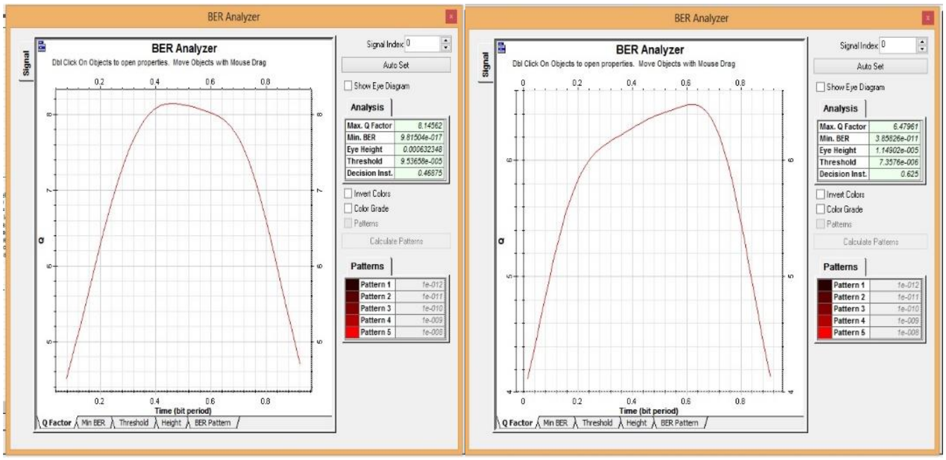

Fig 6.1.1 Range is 100 & 800 m resp.

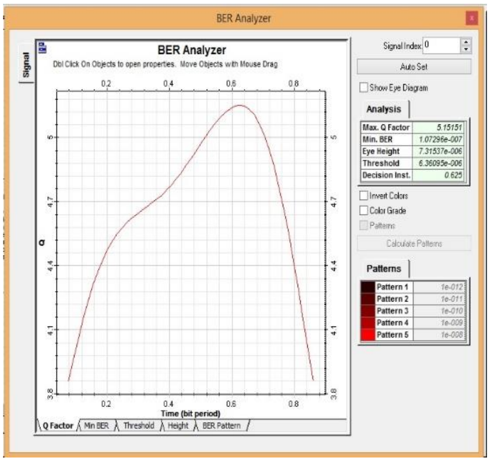

Fig 6.1.2 Range is 900 m.

6.3 FSO with different Modulation Techniques

Firstly, we will take 8-DPSK modulation techniques with different channels i.e. Log Normal and Gamma-Gamma channel with different parameters as shown below:

Parameter	**Value**
FSO Channel Range	500-3500 m
Channel Wavelength	1550 nm
Attenuation	5 dB/km
Power	10 dBm
Bit rate	150 Gbps

Current	10 nA
Responsivity of PIN	1 A/W
Transmitter diameter	5 cm
Receiver Diameter	20 cm
Divergence	2 mrad

Tab. 6.2: Parameters for FSO 8-DPSK Simulation

The 8-DPSK layout as shown below:

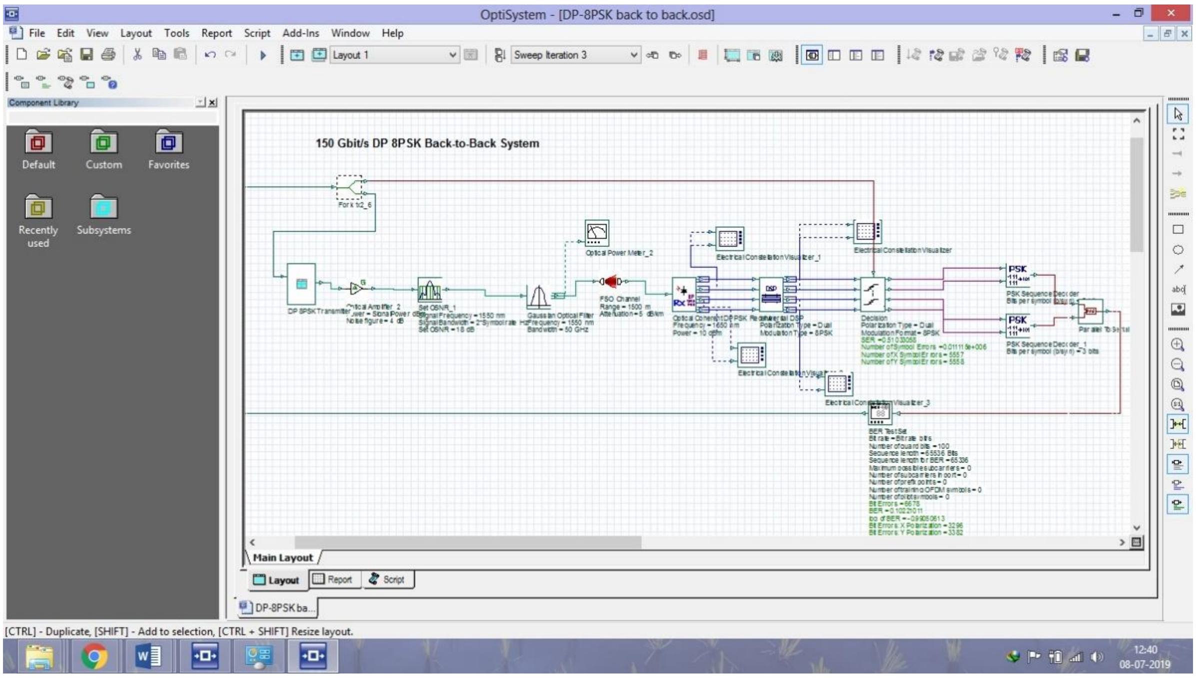

Fig. 6.2 Layout of 8- DPSK

With the help of oscilloscope visualizer, the constellation diagram can be observed for different lengths. The output for constellation diagram for Gamma-Gamma channel as shown below:

The amplitude for the different lengths in Gamma-Gamma Model for 500 m is 1.52, 1000 m is 1.62,1500 m is 1.80. So, through this easily compare as length increases amplitude increasing for the constellation diagram i.e. spreading occurs due to noise in atmosphere.

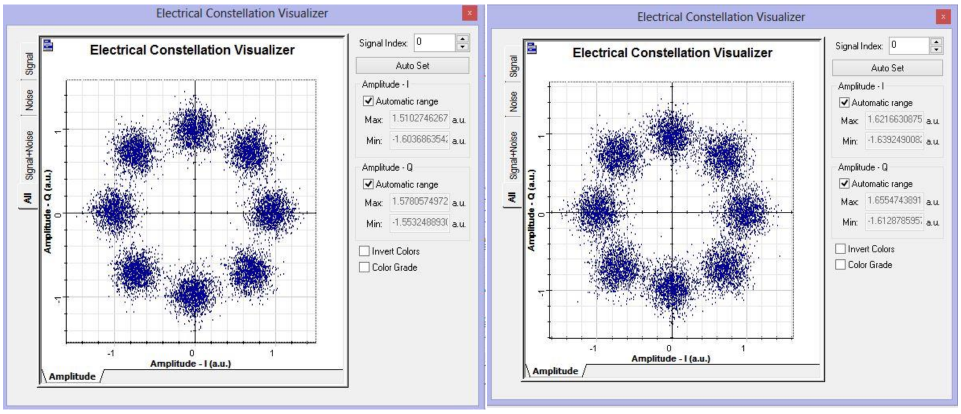

Fig. 6.2.1 8- DPSK Gamma-Gamma model with length 500 &1000 m respectively.

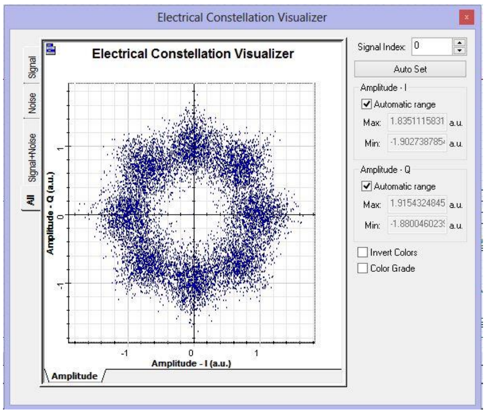

Fig. 6.2.2 8- DPSK Gamma-Gamma model with length 1500 m.

We can also compare BER versus Length for Gamma-Gamma model in 8-DPSK which is as shown below:

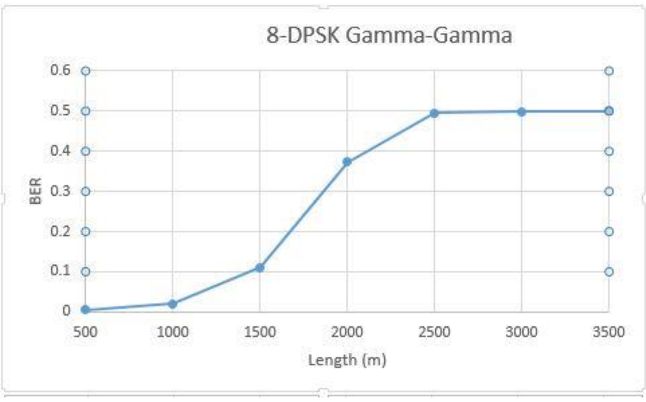

Fig. 6.2.3 8- DPSK Gamma-Gamma model BER versus Length.

With the help of oscilloscope visualizer, the constellation diagram can be observed for different lengths. The output for constellation diagram for Log Normal channel as shown below:

The amplitude for the different lengths in Log Normal Model for 500 m is 1.6262, 1000 m is 1.82,1500 m is 1.92. So, through this easily compare as length increases amplitude increasing for the constellation diagram i.e. spreading occurs due to noise in atmosphere.

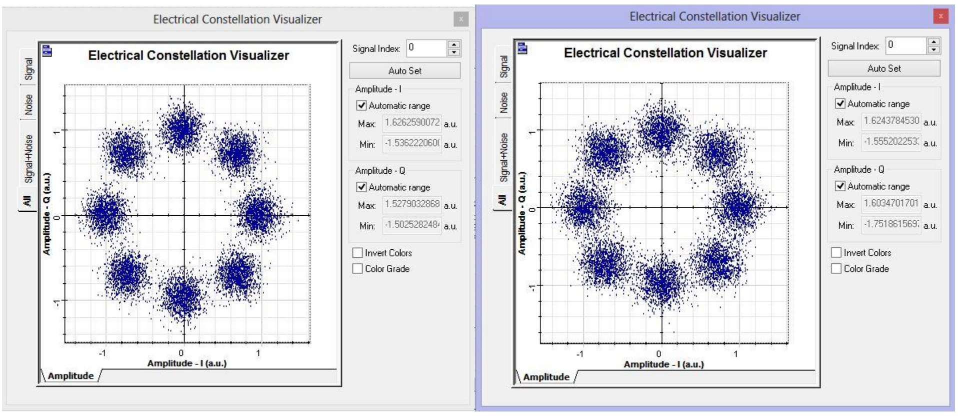

Fig. 6.2.4 8- DPSK Log Normal model with length 500 &1000 m respectively.

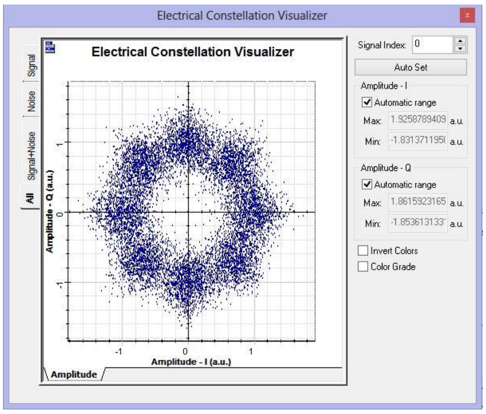

Fig. 6.2.5 8- DPSK Log Normal model with length 1500 m.

We can also compare BER versus Length for Gamma-Gamma model in 8-DPSK which is as shown below:

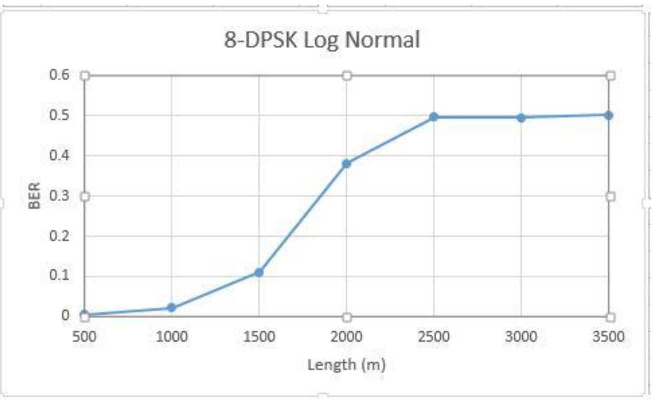

Fig. 6.2.6 8- DPSK Log Normal model BER versus Length.

Now, we will take 8-QAM circular 2 level modulation techniques with different channels i.e. Log Normal and Gamma-Gamma channel with different parameters as shown below:

Parameter	**Value**
FSO Channel Range	200-2000 m
Channel Wavelength	1550 nm
Attenuation	5 dB/km
Power	10 dBm
Bit rate	56 Gbps
Current	10 nA
Responsivity of PIN	1 A/W
Transmitter diameter	5 cm
Receiver Diameter	20 cm
Divergence	2 mrad

Tab. 6.3: Parameters for FSO 8-QAM Simulation

The 8-QAM layout as shown below:

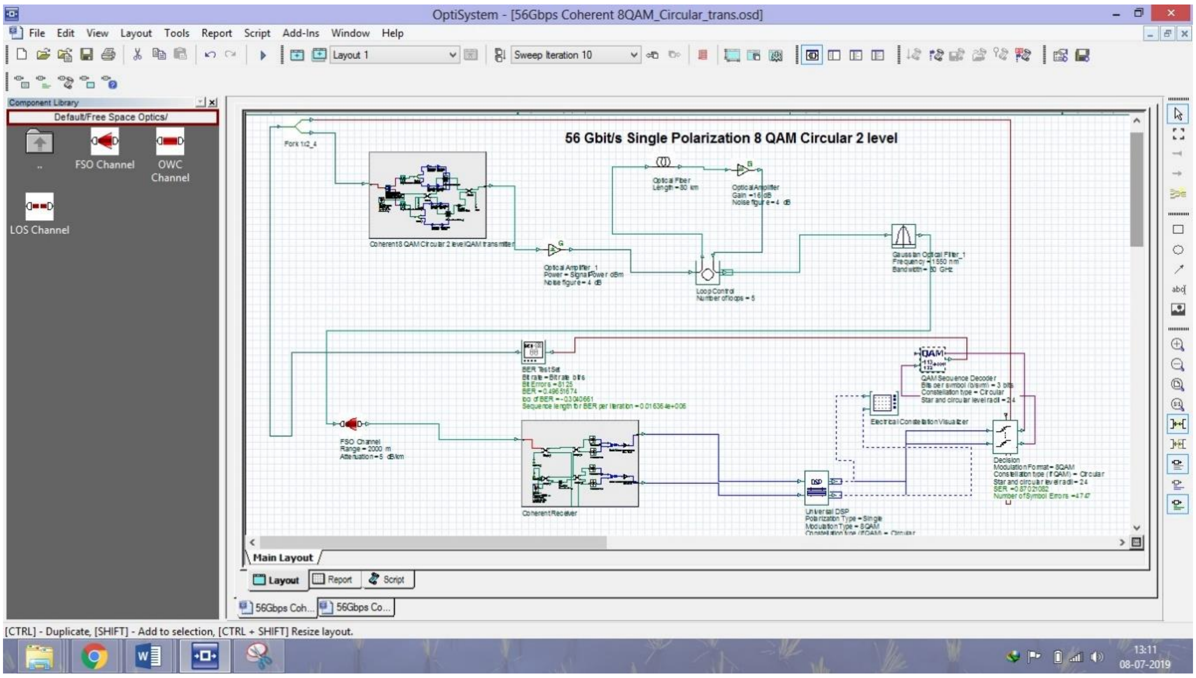

Fig. 6.3 Layout of 8-QAM

With the help of oscilloscope visualizer, the constellation diagram can be observed for different lengths. The output for constellation diagram for Gamma-Gamma channel as shown below:

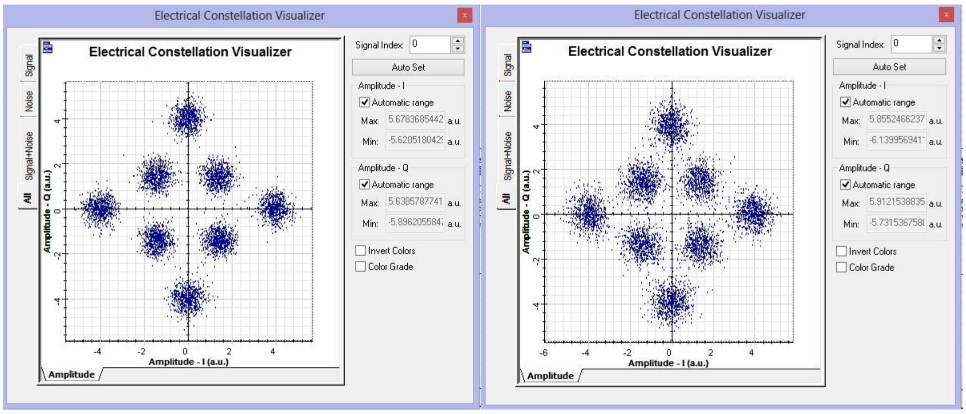

Fig. 6.3.1 8- QAM Gamma-Gamma model with length 200 &600 m respectively.

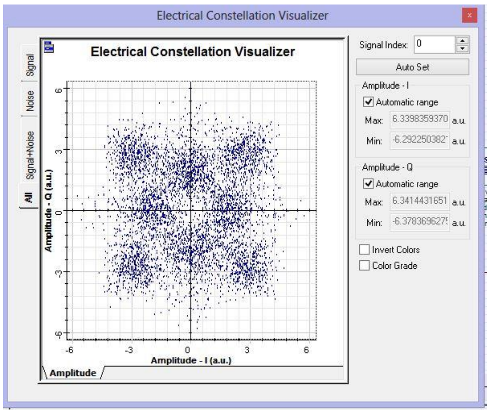

Fig. 6.3.2 8- QAM Gamma-Gamma model with length 1000 m.

The amplitude for the different lengths in Gamma-Gamma Model for 200 m is 5.67, 400 m is 5.81,800 m is 6.42,1000 m is 6.49. So, through this easily compare as length increases amplitude increasing for the constellation diagram i.e. spreading occurs due to noise in atmosphere.

We can also compare BER versus Length for Gamma-Gamma model in 8-QAM which is as shown below:

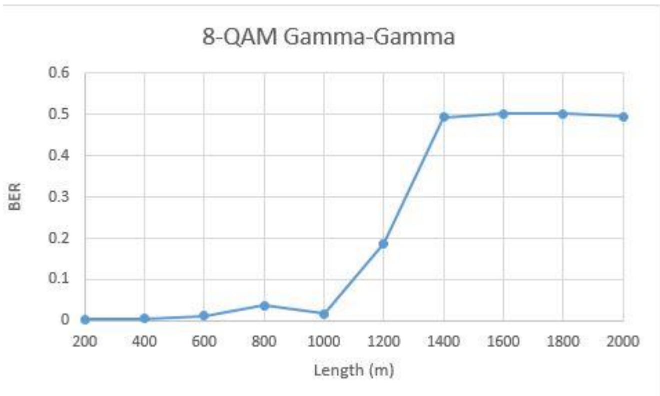

Fig. 6.3.3 8- QAM Gamma-Gamma model BER versus Length.

With the help of oscilloscope visualizer, the constellation diagram can be observed for different lengths. The output for constellation diagram for Log Normal channel as shown below:

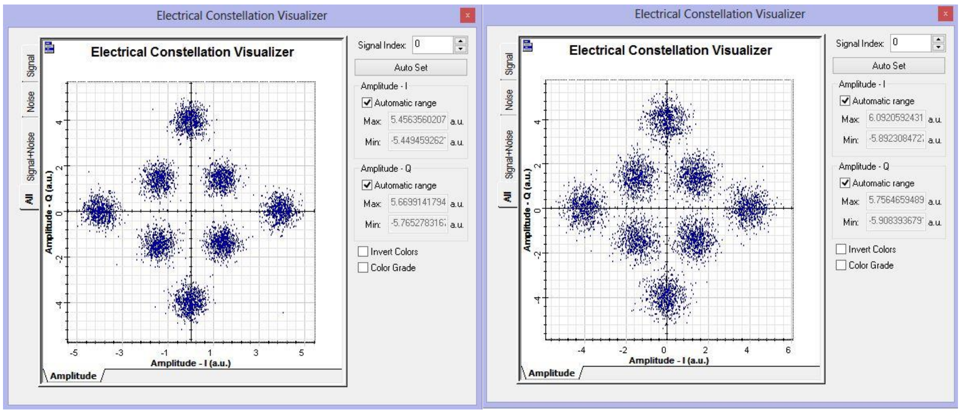

Fig. 6.3.4 8- QAM Log Normal model with length 200 &600 m respectively.

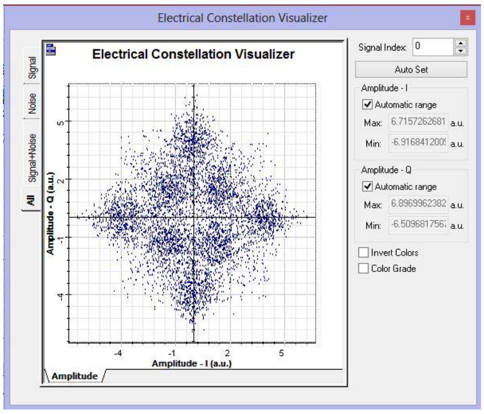

Fig. 6.3.5 8- QAM Log Normal model with length 1000 m.

The amplitude for the different lengths in Log Normal Model for 200 m is 5.74, 400 m is 5.90,800 m is 6.51,1000 m is 6.62. So, through this easily compare as length increases amplitude increasing for the constellation diagram i.e. spreading occurs due to noise in atmosphere. We can also compare BER versus Length for Log Normal model in 8-QAM which is as shown below:

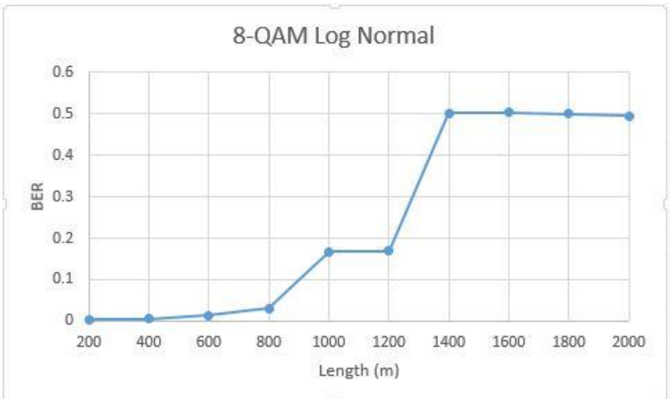

Fig. 6.3.6 8- QAM Log Normal model BER versus Length.

In 8-QAM circular 2-level is far better than 8-DPSK in comparison to different lengths and in terms of BER too. In 8-QAM circular 2-level fading of constellation is less because in this we can easily vary our amplitude having constant envelope. We have observed the results for 56 Gbps data rate for 8-QAM and 150 Gbps for 8-DPSK. As we can observe in 8-DPSK amplitude for 1500m length of FSO is better in Gamma-Gamma channel than Log Normal channel and fading of the constellation is less too.

Conclusion & Future Scope Chapter 7

An Approach with 8-DPSK and 8-QAM modulation techniques with FSO system having different channels i.e. Log Normal and Gamma-Gamma channel observed. As we can observe in 8-DPSK amplitude for 1500m length of FSO is better in Gamma-Gamma channel than Log Normal channel and fading of the constellation is less too. If we compare BER versus Length plot than we can find out BER for Gamma-Gamma model is less. In 8-QAM circular 2-level is far better than 8-DPSK in comparison to different lengths and in terms of BER too. In 8-QAM circular 2-level fading of constellation is less because in this we can easily vary our amplitude having constant envelope. We have observed the results for 56 Gbps data rate for 8-QAM and 150 Gbps for 8-DPSK.

In future we can implement QAM with MIMO technology for better distance and less BER. Different diversity techniques can be observed for an improvement in Q-factor. So, we can transmit our signal to more distance with higher data rates.

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