SYSTEM DESIGN AND PERFORMANCE ANALYSIS OF THE FREE SPACE OPTICS (FSO) SYSTEM IN ATMOHSPHERIC TURBULENCE

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Abstract - *Free space optical communication(FSO) has become more and more interesting as an alternative to radio frequency communication over the last decades. In this paper, performance of free space optics(FSO) communication in the atmospheric turbulence is introduced. Different factors that affected the performance of free space communication channel is presented with different channel model such as Gamma-Gamma channel model and Log-Normal channel model. Research is based on FSO system design and simulation study using mathematical and computer program which based on mathematical relationship of weather factors. Simulation results show the performance of Gamma-Gamma and Log-Normal channel model in Foggy turbulence. It also shows that as the number of Transmitter and Receiver are increased the efficiency of the system increased by decreasing bit error rate(BER). By introduce MIMO topology for FSO system it is possible to degrade the BER for different range and get the accurate transmitted data at the receiver side.*

Key Words: **Free Space Optics(FSO), Gamma-Gamma Channel Model, Log-Normal Channel Model, bit error rate(BER), Multiple Input Multiple Output(MIMO), Atmospheric Turbulence.**

1.INTRODUCTION

The free space optical(FSO) communication also known as optical wireless(OW) communication. As the number of users are increasing significantly, we are seeing a growing demand for bandwidth in a mobile communication. In today's generation, there are many technologies are available in access network like, copper and co-axial cables, wireless internet access, broadband radio frequency and optical fiber. These technologies have some limitations such as congested spectrum, a lower data rate, an expensive licensing, security issues and high cost of installation. Free Space Optics is an age-long technology that transmits the information through the free space optical channel. The FSO communication are attracting attention to resolve the last mile bottleneck issue in local area access network due to their high bandwidth, low cost of implementation, relatively low power consumption and immunity, and security compared with other wireless technology. It refers to the transmission of visible and infrared(IR) beams through the atmosphere to obtain the optical communication. The operation of FSO is basically same as the fiber optics communication. In modern scenario FSO is either use of Light Emitting Diode(LEDs) or Light Amplification Stimulated Emission of Radiation(LASER) as an optical source at the transmitter [1][7].

Section II denotes FSO communication system. Section III gives an information about atmospheric turbulence models. Section IV introduce to MIMO FSO System and sections V and VI gives simulation results and Conclusion to FSO System.

2.FSO Communication System

FSO Communication system is shown in Figure 2.

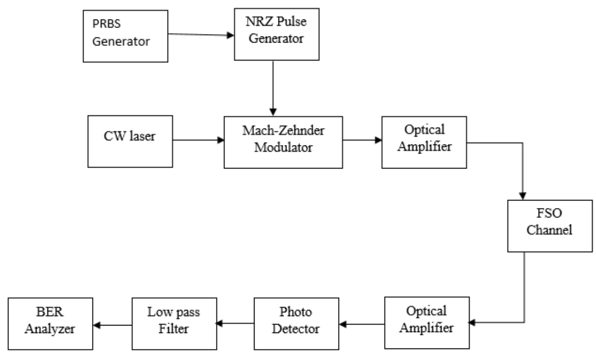

Fig -1: Block Diagram of FSO System

Each module of FSO is described below.

In free space optics laser beam is used to send very high bandwidth data from source to destination through free space atmospheric channel. This can be achieved by applying a modulated narrow laser beam by transmitted through the transmitting antenna and subsequently received at the receiver antenna in the atmosphere. FSO system can be described as:

2.1 FSO Transmitter

Figure shows the basic block diagram of FSO. FSO system contains three main functional elements transmitter, atmospheric channel, and receiver as shown in the figure. At the transmitter, data signal is modulated by modulator using most common method, intensity modulation and the electrical signal is converted into optical signal using optical source like LED or LASER [2][3].

Light sources are used for transmission of data through light. It propagates via free space to receiver and transmits data at higher data rate. LED or LASER can be used as a light source to transmit the data. For optical communication, light sources adopted must have the appropriate wavelength, line width, numerical aperture, high modulation bandwidth. There are number of light sources available but the most commonly used source in optical communication are LEDs and LDs, both of rely on the electronic excitation of semiconductor materials for their operation [7].

2.2 FSO Channel

Communication medium or channel is here free space or air or vacuum. Data transmits through this free space from transmitter to receiver. There are some atmospheric parameters that are affects the transmission. They are Fog, Rain, Dust, Smoke, Physical obstacles etc. [5].

2.3 FSO Receiver

At receiver side, optical detector is used to detect the received data. The detectors are PIN photo detector or APD photo detector. The photo detector is a square-law optoelectronics transducer that generates an electrical signal which is proportional to the square of the instantaneous optical field impinging on its surface. Thus the signal generated by photo detector is always proportional to the instantaneous(received) optical power since the optical signal is generally weak, having travelled through the communication channel, the photo detector must therefore meet stringent performance requirements such as high sensitivity within its operational range of wavelengths, a low noise level and an adequate bandwidth to accommodate the desire data rate [7].

Telescope receives the transmitted signal and directs it towards optical fiber. The optical fiber allows passing of wavelength of the signal and blocks other radiation from the atmosphere. Optical signal converted back to the electrical signal by detector and directed to the amplifier [7].

As shown in the block diagram, transmitter includes the PRBS (Pseudo Random Bit Sequence) generator, NRZ pulse generator, a laser source and Mach Zehnder Modulator. Data generated by PRBS generator is encoded and light modulated using MZM and laser source acts as the carrier source. Then modulated light is amplified using optical amplifiers and transmitted to the receiver through free space optical channel. These signals are received by photo detector by APD and filtered by low pass Bessel filter to filter signal from noise [15].

3.ATMOSPERIC TURBULENCE MODEL

Due to absorption of solar radiation by earth's surface air around surface becomes warmer and less dense causing air temperature to fluctuate randomly. In homogeneities caused by turbulence can be viewed as discrete cells or eddies of different temperature acting like refractive prisms of different size. As interaction takes place between laser beam and turbulent medium results random variation and scintillation of signal carrying beam leads to system performance degradation. Atmospheric turbulence categorized in regimes depending on magnitude of index of refraction variation and inhomogeneity's. These regimes are function of distance travelled by the optical radiation through the atmosphere and classified in three stages weak, moderate, strong and saturation. This turbulence results in signal fading and system performance degradation [7].

The statistical channel model is given by:

$$y = sx + n = \eta I x + n$$

Where, y = the signal at the receiver,

$s = \eta I$ is the instantaneous intensity gain,

η = effective photo-current conversion ratio of the receiver,

I = normalized irradiance,

x = modulated signal

n = AWGN with zero mean and variance $N0/2$

3.1 Log-Normal Turbulence Model

As Log-Normal distribution is simple for mathematical calculations it is widely used for Probability Density Function (PDF). This model is only applicable to weak turbulence conditions and for propagation distance less than 100 meter [7].

Considering Log-Normal Model, PDF of the received optical field *I* is given as *f(I).*

$$f(I)=\frac{1}{\sqrt{2\pi\sigma^2 I}}\exp[-\frac{(\ln(I)-mi)^2}{2\sigma i^2}] \quad I\geq 0$$

Where mi is the mean and σi the standard deviation of

ln (I).

The scintillation index as a function of variance is given by $\sigma_{si}{}^2 = e^{\sigma i^2} - 1$.Hence $\sigma i^2 = \ln(\sigma_{SI}{}^2 + 1)$ And for a given scintillation index, one may compute σ. For weak turbulence, SI falls in the range of [0, 0.75]. As the strength of turbulence increases, multiple scattering effects should be taken into consideration. In such cases, Log-Normal statistics exhibit large deviations compared to experimental data. The detection and fade probabilities which are mainly based on tails of the PDF are not accurately analyzed as Log-Normal PDF underestimates the behavior as compared with experimental results. This in turn affects the accuracy of performance analysis [7].

SNR can be calculated by $\{4 R^2P^2/ (\sigma 1+ \sigma 0)^2\}$. Where, R is responsively of receiver, P is transmitted power and σ1 and σ0 are standard deviation of noise currents for symbols '1' and '0'. Using this equation, SNR v/s BER relationship can be plotted as shown in below figure [7].

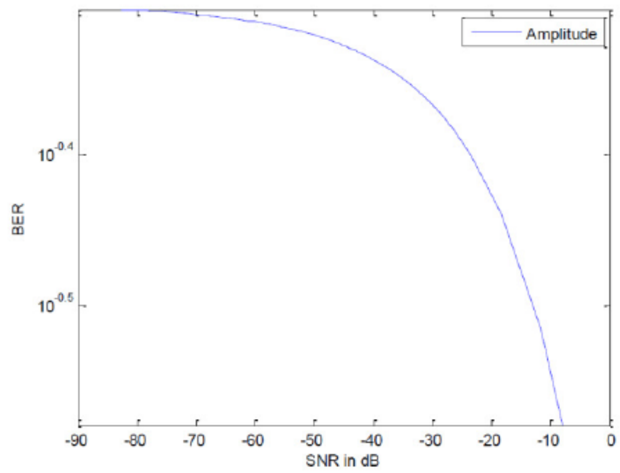

Fig -2: Log-Normal distribution BER v/s SNR curve [7]

3.2 Gamma-Gamma Turbulence Model

As we know Gamma-Gamma Model has weak to strong turbulence condition so that PDF of its intensity I is product of two gamma random variables which represents fluctuations from small and large turbulence [7].

The two random variables are X and Y.

The received Intensity I is;

I = XY

The PDF of I is given by,

$$p(I) = 2\frac{(\alpha\beta)^{(\alpha+\beta)/2}}{\Gamma(\alpha)\Gamma(\beta)} I^{(\alpha+\beta/2)-1} k_{\alpha-\beta}\left(\sqrt{\alpha\beta I}\right) \quad I > 0$$

Where, α = no. of large eddies

β = no. of small eddies

I = Irradiance

Γ(.) = Gamma Function

K (α, β) = Bessel function of Second Order

α and β given by equation,

$$\alpha = [\exp\left(\frac{0.49\sigma i^2}{(1+1.11\sigma i^{12/5})^{7/6}}\right) - 1]^{-1}$$

$$\beta = [\exp\left(\frac{0.51\sigma i^2}{(1+0.69\sigma i^{12/5})^{5/6}}\right) - 1]^{-1}$$

The Scintillation Index (SI) which is use to describe the quantity of turbulence for Gamma-Gamma Channel Model.

$$\sigma_N^2 = \exp\left[\frac{0.49\sigma i^2}{(1+1.11\sigma i^{12/5})^{7/6}} + \frac{0.49\sigma i^2}{(1+1.11\sigma i^{12/5})^{7/6}}\right] - 1$$

4.MIMO IN FSO SYSTEM

In FSO to optimal design can be done by two different MIMO systems. By using four transmitters and four receivers (4Tx/4Rx) FSO system to increase an efficiency of the communication. The other system is two transmitters and

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two receivers (2Tx/2Rx) FSO system. There are two systems, first one is MIMO with two transceivers and second one is MIMO with four transceivers. To observe the behavior of the system under atmospheric effect by calculating BER for different ranges for foggy environment [15].

4.1 SISO FSO System

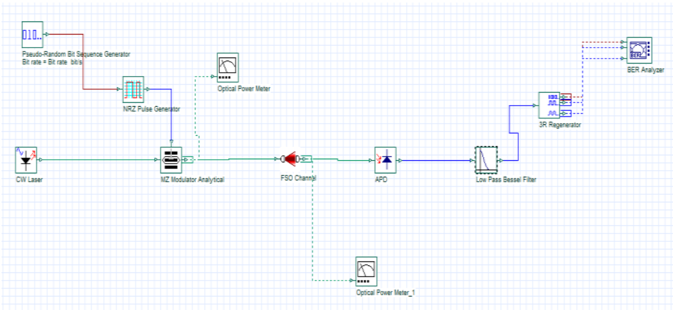

Fig -3: SISO FSO

The fundamental elements that form any FSO system are: transmitter (T*R*x*R*), FSO channel and receiver (R*R*x*R*). The transmitter includes: laser source (650nm, 850nm and 1550nm) was used, PRBS (Pseudo Random Bit Sequence) generator, NRZ (Non-Return to Zero) pulse generator and MZM (Mach Zehnder Modulator). The optical signals from FSO channel are received by APD photodetector. This simulation uses two visualizer's elements namely optical power meter to measure the power received in both dB and Watts, and BER analyzer automatically calculates the BER value, Q-factor and display eye diagram [15].

4.2 2×2 MIMO FSO System

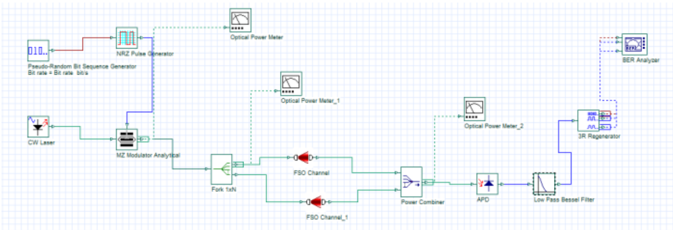

Fig -4: 2×2 MIMO FSO

In figure 4 shown simulation layout of MIMO system with two transceivers, some of components use just in MIMO technique like a fork which is use to duplicate the number of output ports so that each of the signals coming out from fork's output has the same value with the output signal from the previous component connected to it. Fork produced multiple beam of laser, these laser beams are combined by the power combiner. At the receiver side power coming from FSO channel by a power combined and then fed to the optical receiver. Optical power meter and BER analyzer are two visualizers used in the simulation [15].

4.3 4×4 MIMO FSO System

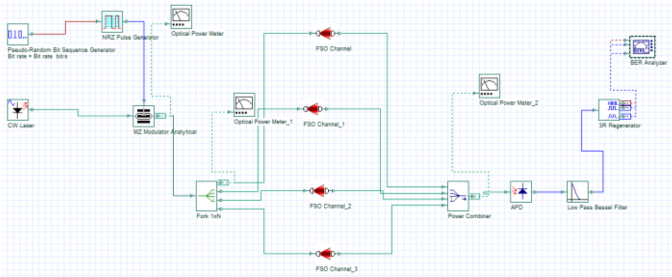

Fig -5: 4×4 MIMO FSO

Figure 5 shows four transceivers FSO system. The working of 4×4 MIMO FSO is same as the two transceivers MIMO FSO.

5.SIMULATION RESULT

The simulation results show the results of BER vs Distance for the Gamma-Gamma turbulence model and Log-Normal turbulence model for SISO, 2×2 MIMO and for 4×4 MIMO FSO system. The wavelength of the FSO system is set to 1550nm. Figure illustrate the comparison between SISO FSO and MIMO FSO in term of BER.

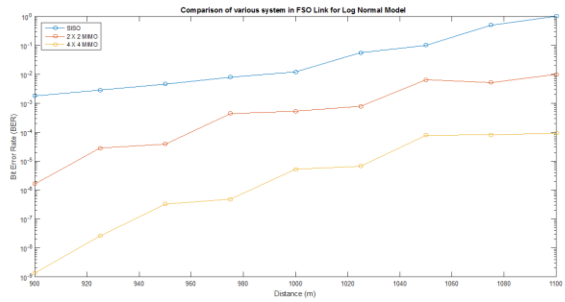

Fig -6: Log-Normal FSO System

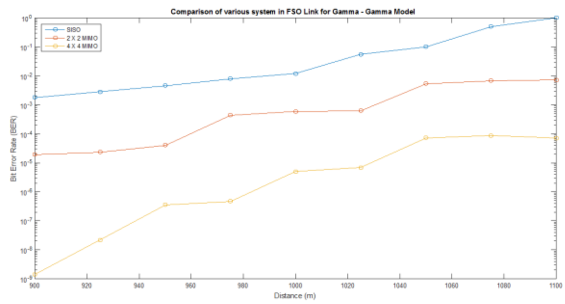

Fig -7: Gamma-Gamma FSO System

Figure 6 and 7 shows the simulation results of Log-Normal and Gamma-Gamma turbulence channel model. The results show that as number of transmitter and receiver are increasing the BER is decreasing with respect to the Distance.

From above analysis, in clear weather and haze or rain the SISO system operate good without problem but when the weather gets worse like fog or snow the link will be failed, so MIMO technique used to improve the communication [15].

In clear weather and haze or rain can get a signal from SISO system, but this signal may have loosed easily under other strong turbulence like foggy weather so MIMO technique will be used that enhance the communication then make the system confirm with the turbulent weather as shown in figure which represent a comparison between SISO and MIMO system under snow and fog conditions by measuring BER for different Distance Between transmitter and receiver [15].

6.CONCLUSION

In MIMO FSO system, low BER is achieved as number of transmitters and receivers are increased. From the analysis of FSO in software we can calculate the required parameters like transmitted power, received power, power losses per range, BER in FSO system. As the range is increased the transmitted power should also be increased for long range successive transmission the power should be kept more. Simulation results concludes that MIMO provides better performance than SISO. It is more reliable and gives more efficiency as compared to the SISO FSO system.

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