Eliminating The Effects Of Fog and Rain Attenuation For Multiplexed Data Transmission On Free Space Optics

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Abstract

Over the last two decades Free-Space Optical communication (FSO) has become more and more interesting as an adjunct or alternative to radio frequency communication. This paper gives an overview of the challenges a system designer has to consider while implementing an FSO system and to overcome its effect. This paper implements multiplexing of data through a free space optical LASER communication system. Calculation of Attenuation due to rain and fog and SNR is also analyzed in this paper. We attempt to overcome their effects on the link. FSO provides data rate up to 2.5 Gbps. Running a high-speed video camera, high quality microphone and enormous data transmission network requires sufficient throughput, security and simplicity which can be best provided by FSO transmission. LASER diode of wavelength 670 nm is used at the transmitter side and a silicon PIN diode as Photo detector is used for receiver. A 2.5 Gbps wireless link is established. Multiplexed data is then retrieved at receiver. The system link is established using simulation software Optisystem and system characteristics is studied.

Keywords: *Free Space Optics (FSO), Automatic Power Controller (APC), Carbonneau model,Kruse's Model, Kim's Model.*

I. INTRODUCTION

Free Space Optics (FSO) offers an attractive alternative technology to optical fiber and radio frequency (RF) communication. It obviates the need for trenching, laying fiber optic cables, securing rights of way and meeting environmental regulations. RF communications, in the licensed band, can provide higher capacity but spectrum licenses are expensive while in the unlicensed band it is limited in bandwidth. FSO links can augment RF communication links with very high (>1 Gb/s) bandwidth. It can also be used to set up communication networks by themselves. Free Space Optics is a line of sight (LOS) technology, which utilizes beams of light to provide point to point wireless connections. The light source is usually laser as this type of light is the most suitable to provide high speed long distance connections. Low speed (typically below 10 Mbps) and short range systems however may use high power LEDs. In some cases of indoor communication FSO may also use non line of sight (NLOS) technology which utilizes an undirected source illuminating the coverage space. The high reflectivity of normal building surfaces scatters the light to produce optical 'ether'. A receiver within the coverage space can detect this radiation, which is modulated in order to provide data transmission.Free space optical communication typically operating in unlicensed Tera-Hertz spectrum bands (wavelength 800–1700 nm), provides several magnitudes of improvement in signal bandwidth over even the highest band signals operating in the RF environment. FSO systems offers extreme security for data connections due to narrow transmission beam which cannot be detected with spectrum analyzers or RF meters. FSO laser transmissions are optical and travel along a line of sight path that cannot be intercepted easily. It requires a matching FSO transceiver carefully aligned to complete the transmission path.

II. FSO CHALLENGES

FSO technology is subject to its own potential outside disturbances. Optical wireless networks based on FSO technology must be designed to combat changes in the atmosphere, which can affect FSO system performance capacity. And because FSO is a line-of-sight technology, the interconnecting points must be from physical obstruction and able to "see" each other.

All potential disturbances can be addressed through thorough and appropriate network design and planning. The primary challenge to FSO-based communications is dense fog. Rain and snow have little effect on FSO technology, but fog is different. Fog is vapour composed of water droplets, which are only a few hundred microns in diameter but can modify light characteristics or completely hinder the passage of light through a combination of absorption, scattering, and reflection. Absorption occurs when suspended water molecules in the terrestrial atmosphere extinguish photons. This causes a decrease in the power density (attenuation) of the FSO beam and directly affects the availability of a system. Absorption occurs more readily at some wavelengths than others. However, the use of appropriate power, based on atmospheric conditions, and use of spatial diversity (multiple beams within an FSO-based unit) helps maintain the required level of network availability. Scattering is caused when the wavelength collides with the scatter. The physical size of the scatterer determines the type of scattering. When the scatterer is smaller than the wavelength, this is known as Rayleigh scattering. When the scatterer is of comparable size to the wavelength, this is known as Mie Scattering. When the scatterer is much larger than the wavelength, this is known as Non-Selective Scattering. In scattering unlike absorption there is no loss of energy, only a directional redistribution of energy that may have significant reduction in beam intensity for longer distances.

III. ATMOSPHERIC ATTENUATION CALCULATIONS

In general attenuation is the reduction in the strength of the signal as it propagates through the medium. It is given as the ratio of the power of the transmitted signal to that of the received signal. The attenuation coefficient,□□ □ □ □, depends on four individual parameters and in a function of wavelength; which are molecular and aerosol absorption coefficient, and molecular and aerosol scattering coefficients [8].

The empirical formula to calculate attenuation coefficient is given by:

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$$\frac{3.912}{V}\left(\frac{\lambda}{550}\right)^{-q} \qquad (1)$$

Where V= Visibility.q= particle size distribution coefficient. A straightforward definition of visibility is the distance at which human eye can see the distinction between a white and black boundary. For calculating the attenuation due to rain we need to know the particle size that can be obtained using several models. For instance, Kruse's model, Kim's model for fog and Carbonneau model for rain, which are explained below

A. Kruse's Model

The particle size distribution coefficient, *q* in the atmospheric attenuation can be defined with a few models [7]. One of them is Kruse model that is widely used in the calculation to determine FSO equipment link budget. The attenuation coefficient, □ □ □ □and Kruse model predict the attenuation for any meteorological conditions; the attenuation will increase with increasing wavelength which implies a preference for equipment working at 1550nm compared to the other wavelengths suggested for FSO equipment.

Kruse model of particle size distribution is:

$$q = \begin{cases} 1.3 & \text{If } V > 50km \\ 1.6 & \text{If } 6km < V < 50km \\ 0.585\, V^{1/3} & \text{If } V < 6km \end{cases} \qquad (2)$$

B. Kim's Model

The evaluation of the parameter *q* using Kruse model for visibility lower than 6km ($0.585V^{1/3}$) was not collected in dense fog. Thus, for visibility, $V < 1$ km, its significance is in doubt. Therefore, a recent study proposed another expression for the parameter *q*, which is called Kim model. It gives the particle size distribution *q* as follows:

$$q = \begin{cases} 1.6 & \text{If } V > 50km \\ 1.3 & \text{If } 6km < V < 50km \\ 0.16\, V + 0.34 & \text{If } 1km < V < 6km \\ V-0.5 & \text{If } 0.5km < V < 1km \\ 0 & \text{If } V < 0.5km \end{cases} \qquad (3)$$

For tropical region which no fog attenuation to consider, only haze attenuation to be calculated, Kruse model is good enough since we do not need to consider for V <1 km since the value as shown in International Visibility Code for severe haze as around 2.5 km in visibility.

C. Carbonneau model

In determining rain attenuation for terrestrial and earth space paths, the following two quantities are required a) The specific attenuation or attenuation per unit length, (A_s) b) The effective path length, (D_{eff})c) Constant *a* and *b*.

The specific attenuation is as shown below:

$$A_s = aR^b \qquad (4)$$

Where $A_s = A/D_{eff}$, a=1.076, b=0.67 (for Carbonneau model).

The effective path length is based on the assumption that along the propagation path the non-uniform rainfall and length, D_{eff} can be modelled by an equivalent cell of uniform rainfall rate [7]. This can be materialized by considering the effective path length by assuming that equivalent rain cell may intercept the link at any position with equal probability. Effective path length can be defined as the average length of the intersection between the cell and path.

IV. EXISTING INFRASTRUCTURE - FSO WITH RF

In existing systems there is a hybrid network infrastructure prevailing where FSO systems are used along with RF systems. During normal weather conditions FSO systems are used. In case of rain FSO systems will be automatically switched to RF systems. This has a lot of disadvantages such as reduction in speed and bandwidth due to RF systems, Increase in overhead caused due to installation of both the technologies at the transmitter side as well as at the receiver, Increase in cost and complexity due to installation and maintenance of both RF and FSO systems. So it would be better to use FSO system at all times in order to alleviate these drawbacks even in the event of rain. But if the same power is used at all weather conditions, the receiver would not be able to sense the signal due to high attenuation that exists during abnormal weather.

In order to use FSO system at all times, we go for an increase in the transmitted power during rain so that the receiver is able to sense the signal with considerable increase in the quality of the information after processing. This overcomes the need to install extra components at the transmitter and receiver. Also the bandwidth and speed are all maintained as in the case of normal weather condition. Our only requirement is the proper design of transmitter that can sense the presence of rain and function accordingly. This implies that only during rain the transmitted power has to be increased to overcome the attenuation that will be encountered on its path. Otherwise normal power output is sufficient.

V. EXPERIMENTAL SETUP

The general block diagram and circuit diagram of the transmitter and receiver are also explained in detail.

A. Basic Principle of operation

The system operation is based on the connectivity between FSO-based optical wireless units, each consisting of an optical transceiver with a transmitter and a receiver to provide full-duplex (bi-directional) capability. Each optical wireless unit uses an optical source that transmits light through the atmosphere towards the photo detector placed at the other end. The optical source converts electrical signal into light signal while the photo detector at the receiver end converts light signal into electrical signal.

The optical communication system consists of a transmitter with a laser beam of a wavelength 650 nm as a carrier in free space, and a receiver that uses PIN diode as detector. In both sides Intensity modulation (IM) technique has been used to transmit audio, video, data signal. The video signal is fed by camera and audio signal by microphone and data transmission network through PC .The transmitted signal is amplified, multiplexed and converted to a modulated intensity of laser beam and sent to the receiver where the laser signal is converted to a weak electrical signal by the detector; the signal will be amplified and converted back to an analogue signal to produce the original transmitted signal, and monitored by AV receiver and PC. The transmission range is 500 m that can be developed letter for longer range.

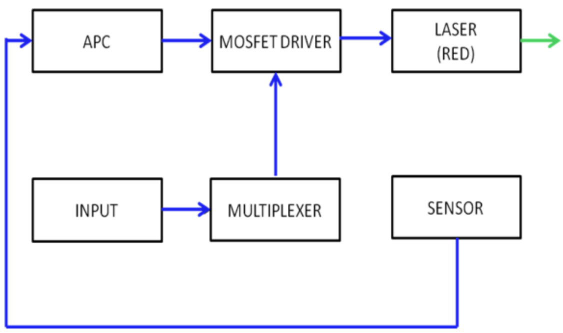

Fig. 5.1 Transmitter Block diagram

B. Transmitter Operation

The block diagram of FSO transmitter is shown in Fig 3.1. The transmitter components are CCD camera, Microphone, PC, multiplexer, sensor, Automatic Power Controller (APC) and a laser source. The Laser source includes both Laser driver and Laser diode. The video signal to be transmitted is captured using the CCD camera; audio signal is taken from microphone, data from PC. The signals are modulated. The driver circuit drives electrical signal towards the LASER diode [2]. The Laser diode converts the electrical signal into corresponding light signal. The laser diode is provided in line of sight with the photo detector at the receiver end. APC provides a lower output in the absence of rain. Here an LDR (Light Dependent Resistor) is used as sensor. In case of rain, the sensor senses the presence of rain by the change in its resistance value. The value of the LDR goes low in case of rain. So it is possible to send a feedback signal to the APC with which a higher current output is used to drive the MOSFET driver. This correspondingly increases the power output from the LASER. Thus during rain, the output increases automatically without requiring any manual assistance.

C. Light Source

In optical communication systems, optical beams generated from light sources carry the information. Laser diodes (LD) and light-emitting diodes (LED) are the most common sources, their small size and their solid structure, and low power requirements are compatible with modern solid state electronics, both are (p-n) junction semiconductors, emits light when forward biased, which cause recombination of holes and electrons that are injected in to the junction, the energy lost in the transition is converted to optical energy in the form of a photon [2]. Photon energy and frequency are related by

$$E = h\,\nu \qquad (5)$$

The radiated wave length is then

$$\lambda = h\,\nu / E_g \qquad (6)$$

Where λ = Wavelength of radiation or emitted laser beam.
h = Planks constant = 6.626×10^{-34} J s.ν = frequency of the radiated light.E_g = the gap energy.

The basic principle of LASER action is the stimulated emission of photons. The probability of stimulated emission is proportional to the intensity of the energy density of external radiation and the induced emission has a firm phase relationship with it, unlike spontaneous emission [6]. Since the spontaneous photons have no phase relations with each other, the output is incoherent. But stimulated emission has the same phase, direction, spectral and polarization properties as the stimulating field and both are indistinguishable in all aspects. Consequently, the laser output is coherent. It is this stimulated emission that comes out of the laser device as laser.

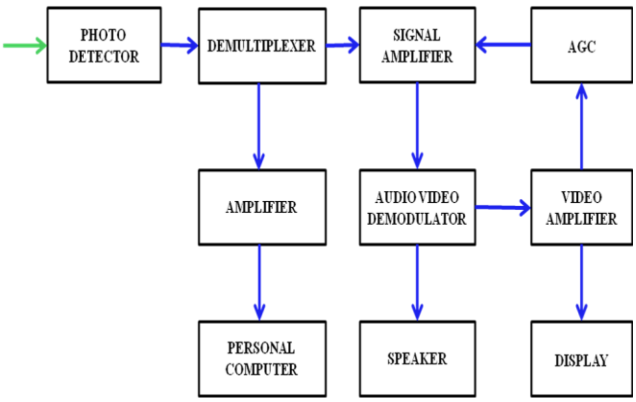

Fig. 5.2 Receiver Block diagram

D. Receiver Operation

The block diagram of FSO Receiver is shown in Fig. 5.2. The Receiver component includes Collimating Lens, PIN photo detector, signal amplifier, demodulator, video amplifier and TV monitor, Speaker, PC. The collimating lens focuses the received light signal towards the photodiode. The photodiode converts the incoming optical signal into corresponding electrical signal. It is then demultiplexed. The signal amplifier is to amplify the weak electrical signal. The electrical signal is then demodulated by the audio video demodulator. The recovered audio video signal is amplified and then connected TV monitor and speaker. Parallely data signal is amplified and then given to PC.

E. Photo detectors

A photo detector is an Opto-electric device that converts received optical power into electrical power with linear response. There are two types of detectors used in free space optical communication systems. Both are semiconductor devices, they are: Positive Intrinsic Negative (PIN) and Avalanche Photo Diode (APD).

In most applications PIN is the preferred element in the receiver. This is mainly due to the fact that it can be operated from standard power supply, typically between (5-15V); it has lower cost, lower noise, and no gain. APD devices have much better sensitivity than PIN. In fact, they have high gain (5 to 10 dB), more sensitivity. However they cannot be used on a (5 V) printed circuit board. They also require a stable power supply, typically between 100-400V. This makes their cost higher. APD devices are usually found in long haul communication links. The output of the detector is a very weak signal, thus the photo diode circuitry is followed by one or more amplification stages. This is to amplify the signal to yield an electrical signal representing the original input.

VI. RESULTS AND CONCLUSION

A. Simulation results

We have simulated the FSO link using Optisystem with the parameters chosen [8]. Since the components for rain and fog are not available in Optisystem we have written programs in MATLAB and linked them with Optisystem to complete the simulation of having rain and fog along the link. We have considered an attenuation of 1 dB/km and calculated OSNR (Optical Signal to Noise Ratio) at the transmitter and receiver, noise figure, optical power output and also analyzed the BER (Bit Error Rate).LASER frequency are chosen as 447.451 THz with input power of 5 mW and line width of 10 MHz

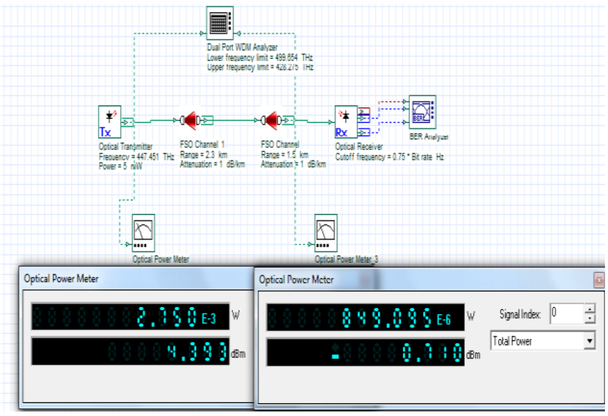

Fig 6.1 FSO link Layout – Under normal conditions

During the normal conditions the input optical power is 4.393 dBm, the output optical power is -.710 dBm from which the video can retrieved.

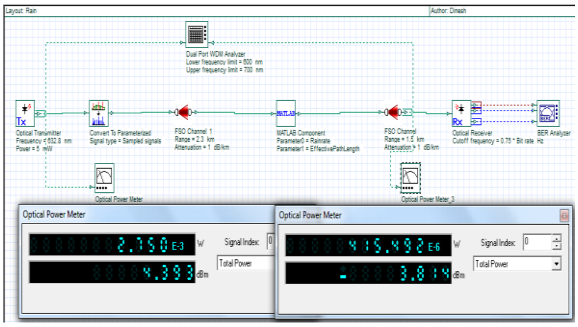

Fig 6.2 FSO link during rain

During rain the FSO channel is attenuated by rain. The rain component is coded in matlab and simulated along with optisystem the output optical power is -3.814 dBm. The video signal is distorted and clear image is not obtained.

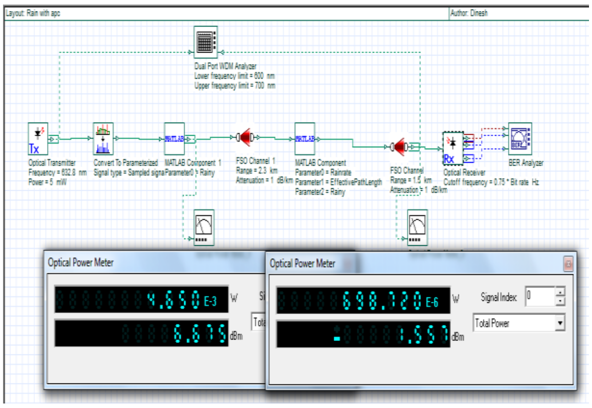

Fig 6.3 FSO link during rain with APC employed

To obtain a clear video the power of the laser has to be increased accordingly to withstand the attenuation due to rain. The power is increased by APC.With APC employed the output power is -1.557 dBm, which is sufficient to produce a clear video. The eye diagram also gives a clear pattern which verifies the result.

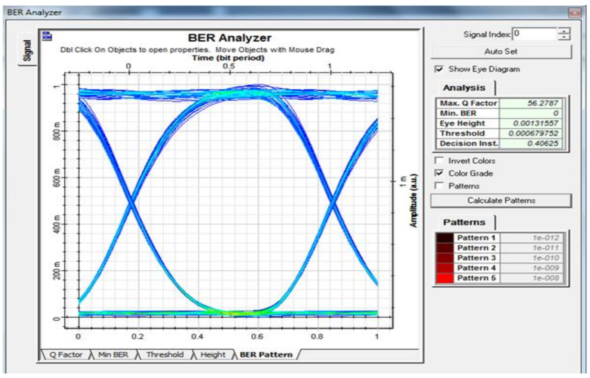

Fig 6.4 BER analysis

B. Conclusion

In this paper a 2.5 Gbps FSO link for multiplexed data is achieved. The paper is tested and demonstrated for a distance of 500 meter though it can be extended up to 16 km, essentially due to space constraints in the laboratory. Also we have calculated OSNR, Noise figure, Gain, Optical power, analyzed the spectrum and BER using Optisystem 7.0. We have achieved what we set out to do- to implement data multiplexing through FSO and to eliminate the effects of Fog and Rain attenuation on the link. With further research and development it is hoped that it can be used for medical, defence, LANs and various other applications over greater distances and during all weather conditions.

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