Free Space Optical Communication: The Main Challenges and Its Possible Solution

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Abstract— Free Space Optics (FSO) is a promising solution for very high data rate point-to- point communication. Recently, it has received significant attention as a possible alternative to overcome the bottleneck connectivity problem and as a supplement to more conventional RF/microwave links. FSO communications has become attractive for a number of reasons including unlicensed spectrum and a narrow beam width. Moreover, FSO becomes the best solution to solve the problems occurred in conventional wireless system by using optical fiber because it uses laser light to transmit data between two points. The FSO uses beam of light to provide optical connection that can send and receive video, voice, and data information. In this paper Free Space Optical communication concept will be introduced. In addition, the performance of FSO communication link will analysis and illustrates its main challenges and it possible solutions.

Index Terms— Atmospheric Turbulence, Buffering, Fso, Fso link performance, Retransmission.

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1 INTRODUCTION

THE free-space optical communication (FSO) is an optical communication technology that uses light propagating in free space to transmit data for telecommunications or computer networking. "Free space" means air, outer space, vacuum, or something similar. This contrasts with using solids such as optical fiber cable or an optical transmission line. The technology is useful where the physical connections are impractical due to high costs or other considerations [2]. FSO system is cost-effective and an attractive solution for high-speed communication systems and provides very large bandwidth where a data rate of 100 Gbit/s can be achieved over a distance of 1-4 km. Furthermore, propagating laser radiation over the atmosphere termed FSO communications is attractive for a number of reasons including unlicensed spectrum and a narrow beam width [9]. In the Free Space Optical communication, the technology is fundamentally based on transmitting optical signal into the free space and the air or vacuum space acts as the medium for signal transmission., It offers data rates comparable to optical fiber communications but at a fraction of its deployment cost. Furthermore, it's extremely narrow laser beam width offers spatial multiplexing and multiple links capabilities in a given location [1]. Conventional wired and radio frequency (RF) wireless communications suffers "last-mile" data transmission, where local area network (LAN) based FSO system has the potential to solve the "last-mile" problem for the foreseeable future as a bandwidth in excess of 2THz. Besides high data transfer rate, a direct line-of-sight FSO link offer numerous advantages compared to the conventional systems [3].Moreover, FSO link consumes relatively low power and also provide greater security to the data as the data carrying light rays are confined to very narrow area as the light beam is of small diameter. The FSO signals are also less sensitive to the electromagnetic interferences [9]. FSO system is like optical system, the main components of the transmitter

and receiver are modulator, optical source, optical detector and a demodulator. Basic block diagram of a Free Space Optical system is given in the Fig.
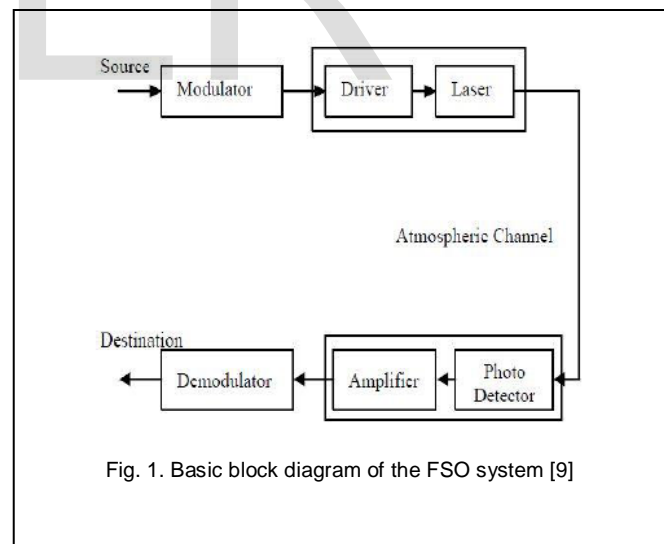

Fig. 1. Basic block diagram of the FSO system [9]

The modulation and the demodulation both are done in the electrical domain and commonly used modulation techniques used are Pulse Position Modulation (PPM) and On-Off Keying (OOK). Apart from these modulation techniques, the research is going on to implement other modulation techniques along with some coding techniques to get the optimum performance of the system. Free-space point-to-point optical links can be implemented using infrared laser light, although low-data-rate communication over short distances is possible using LEDs. Infrared Data Association technology is a very simple form of free-space optical communications [6]. The various

issues related to the free space optical system are- atmospheric turbulence, scintillation, fog, smoke, building sway etc. These are the parameters which affect the performance of the system. In this paper, FSO concept and its link performance are mainly discussed. Atmospheric turbulence is described using the gamma–gamma probability distribution. Lastly, several of FSO impairments are declared.

2 FREE SPACE OPTICAL LINK PERFORMANCE

The performance of an FSO link is primarily dependent upon the climatology and the physical characteristics of its installation location. The transmitted optical beam traversing the atmosphere can be absorbed, scattered or displaced depending on the atmospheric condition, thus setting the fundamental limits of FSO systems. In general, weather and installation characteristics that impair or reduce visibility also affect FSO link performance. A typical FSO system is capable of operating at a range of two to three times that of the naked eye in any particular environmental condition [5]. The overall system performance of a link is quantified using a link margin derived from the link equation. This equation is analogous to the link equation for any radio frequency (RF) communication link. Starting with the transmit power the designer identifies all link degradations and gains to determine the received signal level. The received signal level is then compared with the sensitivity of the receiver, thus giving the link margin [10]

2.1 Channel With out Atmosperic Disturbance

In the basic free-space channel the optical field generated at the transmitter propagates only with an associated beam spreading loss. In this system the performance can be determined directly from the power flow. The signal power received P_R [W] depends on the transmit power P_T [W], transmit antenna gain G_T receives antenna gain G_T the range loss G_r, and system-dependent losses Asystem link:

$$P_R = P_T * G_T * G_R * A_{System\ link} \qquad (1)$$

Assuming a Gaussian beam under filling the transmit aperture, the transmit antenna gain G_T is:

$$G_T = \frac{32}{Q^2} \qquad (2)$$

Where Q [rad] is the full-angle e^{-2} divergence of the transmit beam. The range loss G_R depends on the link propagation distance L and is given by:

$$G_R = \left(\frac{\lambda}{4\Pi L}\right)^2 \qquad (3)$$

Further, the receive antenna gain, with telescope aperture diameter (antenna size) D, is given by:

$$G_R = \left(\frac{\Pi D}{\lambda}\right)^2 \qquad (4)$$

The Asystem link reflects all the other system-dependent losses. It includes losses due to link misalignment, telescope losses, losses due to splitting out light for tracking systems, etc. Because of the absence of atmospheric effects the link margin Mlink in dB is given by [10]:

$$M_{link[dBm]} = P_{R[dBm]} - S_r \qquad (5)$$

Where: received power P_R [dBm] must be given on a logarithmic scale. Sr [dBm] is the required power at the receiver to achieve an expected communication performance, also called receiversensitivity.

2.2 Atmospheric Effects

It is well known that clouds, rain, snow, fog, haze, pollution are atmospheric factors that affect our viewing of distant objects. These same factors also affect the transmission of a laser beam through the atmosphere.As transmission through clouds or heavy fog or haze is normally not possible, because the attenuation exceeds several tens of dB/km. The signal under clear-sky weather conditions is attenuated because of extinction caused by air molecules and aerosols. The transmittance T of laser radiation that has propagated over a distance L is described by the Beer's law [10]:

$$T = \exp(-\alpha_s * (\lambda) * L\ [km]) \qquad (6)$$

The positive extinction coefficient ($\alpha_s*\lambda$) describes the extinction level of the medium. Atmospheric trace gases lead to strong and broad absorption bands, each consisting of a multitude of fine absorption lines. Based on the spectral distribution of these bands, the so called atmospheric optical transmission windows with low signal losses of the propagating beam can be calculated by evaluating thousands of absorption lines in the spectral range from 0.3 μm to14 μms [10]. In addition to absorption, scattering has also to be taken into account. This can be described by the Rayleigh scattering coefficient. Generally, scattering effects decrease monotonically with wavelength and altitude. Even in optical windows some extinction must be considered, e.g. due to Rayleigh scattering. A rough estimate for the clear-sky extinction is based on the meteorological parameter visibility V.

3 ATMOSPHERIC TURBALANCE

Laser radiation experiences amplitude and phase fluctuations due to atmospheric turbulence when it propagates through the vacuum. This effect is the consequence of random variations in the atmospheric index of refraction due to corresponding changes in atmospheric temperature. According to [7], the induced thermal gradients may be viewed as close-packed spherical regions or eddies having statistically varying diameters and indexes of refraction. Atmospheric turbulence is well studied in the literature and various models exist to describe it. The most used model is apparently the log normal turbulence. This model has gained considerable attention in the literature because it is mathematically convenient and tractable, but the model is only valid in single scattering event characterizing weak turbulence. When multiple scatterings are experienced especially in longer link ranges, the incident wave becomes increasingly incoherent and log normal model becomes invalid [7].

3.1 Gamma-gamma modeling

The gamma-gamma model of turbulence is based upon such modulation process which assumes that the small scale and large scale effects are responsible for the changes occurring in the path of radiated light signal travelling through turbulent atmosphere. This channel model also considers a region between transmitter and receiver which is known as Fresnel zone. The Fresnel zone is an elliptical area between transmitter

and receiver around the line-of-sight path between them. The Fresnel zone helps in carrying the strongest signal to the receiver. The eddies cells, which are smaller than the Fresnel zone result in small signal effect, i.e. scattering and the eddied cells larger than the Fresnel zone result in a large scale effect known as refraction [5].

The gamma-gamma turbulence model proposed by Andrews et al is based on the modulation process where the fluctuation of light radiation traversing the turbulent atmosphere is assumed to consist of small scale and large scale effects. The eddies cells, which are smaller than the Fresnel zone or the coherence radius result in small signal effect, i.e. scattering and the eddied cells larger than the Fresnel zone result in a large scale effect known as refraction [5]. The small scale eddies are assumed to be modulated by the large scale eddies. Consequently, the received radiance is defined as the product of two statistically independent random processes I_x and I_y.

$$I = I_x * I_y \qquad (7)$$

Ix and Iy arise from the large scale and small scale turbulent eddies respectively. The gamma-gamma model for the probability density function (pdf) of receiving irradiance fluctuation which is based on the assumption that both the large and small scale effects are governed by the gamma distribution is therefore given by [6].

Based on the atmosphere turbulence model adopted here and assuming strong turbulence, we can obtain the approximate analytic expression for the covariance of the log-amplitude fluctuation of plane and spherical waves which is also known as Rytov variance, given by [8]:

$$\sigma_B{}^2 = 1.23 \, C_n{}^2 \, K^{\frac{7}{6}} \, L^{\frac{11}{6}} \qquad (8)$$

3.2 Free Space Optical Impairments

Fso suffers many factors that degrade the performance of the system like rain, scintillation, fog, smoke, building sway etc. The research is going on to make the FSO system more efficient and accurate.

3.2.1 Rain and Snow attenuation

The rain and the snow are one of the factors that restrain the line-of-sight link between the transmitter and the receiver. The snow is divided into two types-wet snow and dry snow. The amount of attenuation due to wet snow is higher than the attenuation occurring due to dry snow [3]. The dry snow effects on the low snow rate, whereas wet snow effects at high snow rate. The amount of attenuation decreases as the visibility increases during the snowfall.

3.2.2 Scintillation

Atmospheric scintillation can be defined as the changing of light intensities in time and space at the plane of a receiver that is detected a signal from a transmitter located at a distance. The received signal at the detector fluctuates as a result of the thermally induced changes in the index of refraction of the air along the transmit path. These index changes cause the atmosphere to act like a series of small lenses that deflect portions of the light beam in and out of the transmit path. The time scale of these fluctuations is on the time scale of these fluctuations are the order of milliseconds, approximately equal to the time that it takes a volume of air the size of the beam to move across the path, and therefore is related to the wind speed [3].

3.2.3 Alignment

One of the key challenges with FSO systems is maintaining transceiver alignment. FSO transceivers transmit highly directional and narrow beams of light that must impinge upon the receive aperture of the transceiver at the opposite end of the link. A typical FSO transceiver transmits one or more beams of light, each of which is 5–8 cm in diameter at the transmitter and typically spreads to roughly 1–5 m in diameter at a range of 1 km. Adding to the challenge is the fact that FSO receivers have a limited FOV, which can be thought of as the receiver's "cone of acceptance" and is similar to the cone of light projected by the transmitter. For a FSO link to function, it is very important that both the transmitted beam of light and the receive FOV cone encompass the transceiver at the opposite end of the link [3].

3.2.4 Free Space Path Loss

Free-space path loss (FSPL) is the loss in signal strength that would occur in a line-of-sight path through free space (usually air), with no obstacles nearby to cause reflection or diffraction. It does not include factors such as the gain of the antennas used at the transmitter and receiver, nor any loss associated with hardware imperfections [3]. The equation for free space path loss (FSPL) and the effect of link length are given below:

$$FSPL = \left(\frac{4\Pi d}{\lambda}\right)^2 \qquad (9)$$

4 THE MAIN POSSIBLE SOLUTION

In fact, all modalities of free space optical communication can offer solutions to the last mile problem, affording flexible and rapid connectivity. However, radio frequencies carry heavy tariffs and licensing fees. We have outlined the primary challenges limiting the extensive implementation of FSO and in the next subsections we present some alternative solutions to these. However, on a macro level, a link is either operational or not depending on whether or not the signal-to-noise ratio (SNR) is too low. If the link operation is inadequate, there may be alternative ways to transmit the data by circumventing the failed link. Such approaches can he generalized as solutions at the net-work layer, However optical wireless networks have features that demand special consideration. A few solution is below for a broad review of optical network technology and solution the reader is referred to [12]

4.1 Buffering

When atmospheric transmission is low and the signal is severely attenuated (e.g., due to fog), there is likely to be considerable error in detection. In these cases it may be wise simply to store the data and transmit it later when the environmental obstruction has passed. This tactic is familiar with all networking environments, but the vast data rates of optical communication systems would result in huge volumes of storage for even brief outages. Therefore, a part-optical part-electronic buffer would probably be needed to cope with the amount of data to be stored [13]. If the link capacity is reduced, but not inoperative, it is possible to suspend low-priority transmissions while selectively continuing with high-priority data. For instance, email transmissions could be buff-

ered even for several hours in severe weather conditions. Precedence could then be given to real-time voice data or transmissions attributed the high quality of service (QoS).

4.2 Retransmission

Another alternative solution at the networking level is to retransmit the data. This may be performed when the reception has been found to be faulty or is anticipated to be defective. Retransmission can be particularly helpful when there is strong turbulence in the atmosphere, since repeated transmissions may increase the probability of correct detection. In the presence of severe building sway, retransmission is likely to succeed since the building is effectively entering and exiting the transmission path, and the accumulation of signals can be sufficient for successful communication.

4.3 Rerouting Transit Paths

Networking between nodes can alleviate communication problems by enabling alternative routes from sender to recipient when the direct connection is disabled. Clearly, only local malfunctions of a link can be combated, and then only on the assumption that sufficient other participant links are operative to close the loop between transceivers. The availability of individual links can he validated continuously using sophisticated protocols to optimize efficiency. The best route can he selected, while taking into account other traffic demands. Rerouting requires point-to-multipoint transceivers, with either dedicated transmitters for each link or pointing mechanisms. A high level of redundancy and short link ranges increase the networks rerouting capabilities.

5 CONCLUTION

Now that FSO communication is a reality, creative solutions are sought to combat the main problems encountered. In this paper we have reviewed some of the prominent ideas published in the professional literature, the Free Space Optics System (FSO) is becoming the solution for conventional wireless system which face problems of last-mile service providing. In this paper the combined fundamental of FSO, link performance, impact of atmospheric turbulence, path loss factor and free space optical communication system is presented. The basic characteristics of a laser beam provide the following advantages of FSO links:

A narrow beam guarantees high spatial selectivity so there is no interference with other links, the high available bit rate allows them to be applied in all types of networks, the optical band lies outside the area of telecommunication regulation; therefore no license is needed for operation, the small size and small weight of optical terminals enables links to be easily integrated into mobile systems.

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