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Free Space Optics: Atmospheric Effects & Back Up

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Abstract

The Free space optical communication technology tries to fulfill rising need for high bandwidth transmission capability link along with security and ease in installation. Due to their high carrier frequency in the range of 300 THz, it provides highest data rates of 2.5 Gbps which can be increased to 10 Gbps using Wavelength Division Multiplexing (WDM). FSO link is license free, secure, and easily deployable and offers low bit error rate link. These features motivate to use FSO as a solution to last mile access. Along with these attractive features of FSO, a well-known disadvantage of (FSO) is its sensitivity on local weather conditions which results in loss of optical signal power. In this paper we will discuss performance analysis of FSO in different weather conditions.

Keywords: FSO, WDM, High Bandwidth Transmission, Optical Communication, Optical Signal Power.

I. Introduction

Transmission of information by using light is not a new idea. In the late nineteenth century, Alexander Bell expanded his "phone-phone" communication which modulated by sunlight. FSO is a wireless technology that transmits data via laser beams. FSO uses light to transmit data between buildings that have cleared a line of sight (LOS). FSO is a line of sight technology that uses devices such as lasers to establish connectivity for video and voice communication. Currently, it can allow up to 2.5 Gbps of data rate but can be increased to 10 Gbps using Wavelength Division Multiplexing (WDM). FSO is based on connectivity between two stations consisting of optical transceiver to achieve full duplex communication. The light pulses are transmitted through the atmosphere in a small conical shaped beam by the means of low powered lasers or LED's. Figure 1 shows the basic diagram of FSO.

However, the quality of service of a FSO link in the atmosphere is strongly influenced by weather conditions [1]. Weather conditions like fog, rain and snow results in loss of optical signal and signal fading [2].

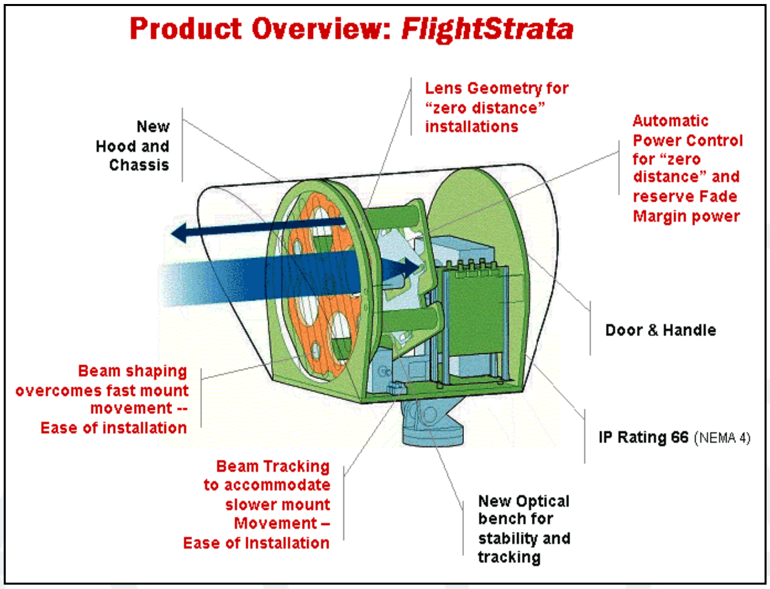

Fig.1: Basic Diagram of FSO

II. Atmospheric Effects on FSO

The attenuation of an optical beam as it propagates through the air is given by the Beer-Lambert law as- $I(x) = Io\ e^{-\alpha x}$, where Io is the initial optical intensity in watts, I(x) is the intensity after the beam has travelled a distance of x meters, and α is the attenuation coefficient of the medium in m^{-1}. Attenuation of the atmosphere can be caused by several factors, including absorption of the beam via molecules in the atmosphere and attenuation of the beam due to Rayleigh or Mie scatter with molecules or aerosol particles in the air.6 For most FSO applications, Mie scatter (especially due to fog) is often dominant. Signal Propagation is effected by Fog, clouds and dust particles but major factor of attenuation is Rain. It was found that attenuation linearly increases with rainfall rate, and the mean of the raindrop sizes increases with the rainfall rate and is in the order of a few mm [3].

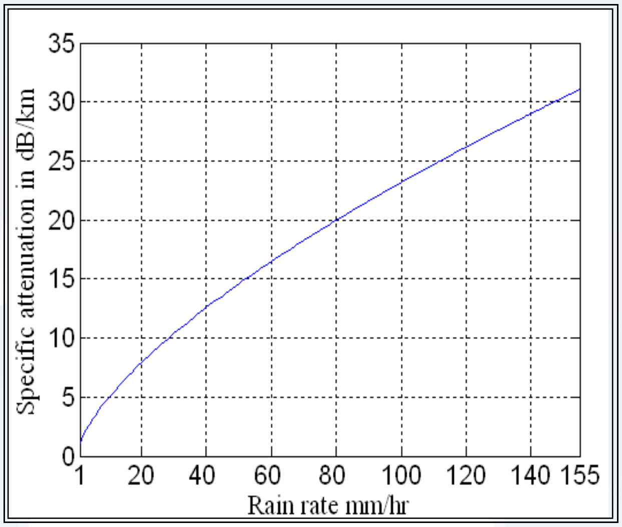

Fig.2: Specific attenuation of optical wireless links for different rain rate.

Figure 2 shows the effect of rain on the bases of Rain Rate mm/hr v/s Specific attenuation in dB/km which indicates the attenuation of signal as rain rate increases. Free Space Optics (FSO) links are highly weather dependent that reduces the link availability. Fall of the received optical power below the receiver sensitivity threshold introduces a fade that can be termed as a short-term or a long-term fade depending upon the time duration. Long-term fades usually occur during fog, snow and rain events and last from few minutes to several hours. In this contribution we would focus our discussion only on the long term fades introduced by fog and snow conditions to the FSO link in free space. The fog, rain or snow particles reflect the light pulse to the receiver element, and after amplification and shaping of the output pulse, the signal is ready for the further processing. The sensor's pulse cycle is high enough to test the particle density by examining the variation of the consecutive output pulses. In case of moderate fog conditions the peak voltage falls down between two or more detection, but the dense fog may cause constantly high output pulse peaks. This is shown in figure 3.

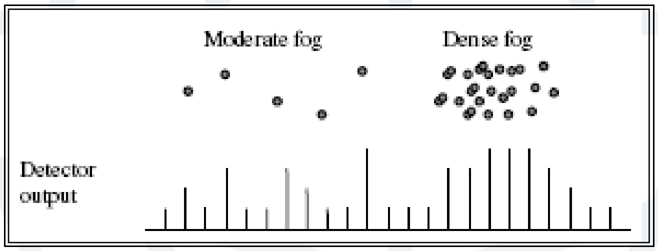

Fig.3: Moderate Fog v/s Dense Fog

Figure 4 shows the attenuation curve due to haze for different visibility.

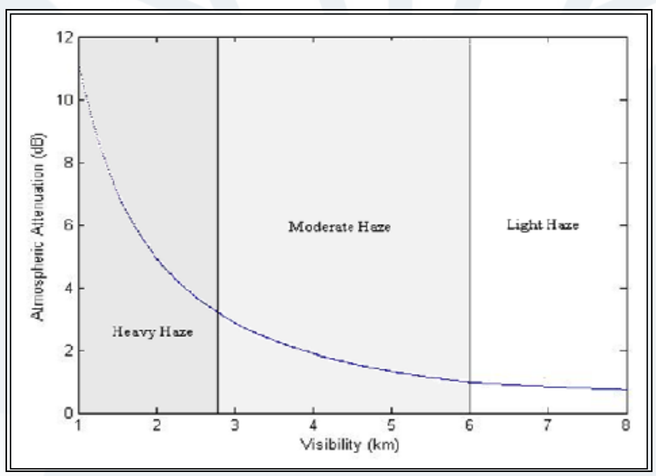

Fig.4: Attenuation due to haze for different visibility

V is visibility range in km and λ is transmission wavelength in nm. For rain, an accepted empirical model based on the visibility range estimated is:

$$\alpha_{Rain} = 2.9/V$$

The attenuation for snow based on visibility range estimate is given below:

$$\alpha_{Snow} = 58/V$$

It is important to remember that attenuation due to snow can be more severe than the attenuation even in case of severe rain, for its much larger flake size and for its composition being a combination of water, ice and air molecules [4].

A. *Case Study of Malaysia*

Rains in Malaysia appear throughout the year, but they peak during monsoon seasons, which fall on different months for different parts of Malaysia [6] (east coast – November, December and January; the north western region – January, February, June and July; the southwest coastal area – May to August and October and November; the rest of the Peninsula– from October to November and from April to May). Average rain intensity for Malaysia exceeding 0.01% of the year is 120 mm/hr, which yields attenuation of 28dB/km. Therefore for carrier class signal (with availability of 99.99%) link length would be limited to only about 800 m [7].

B. *Back up for FSO*

Hybrid networks consisting of Free Space Optics (FSO) link and back up link in the GHz frequency range renders high availability besides providing comparable data rate. The backup link should be nearly immune to weather attenuation for achieving carrier class availability.

The answer for the most cost-effective FSO back-up solution would be to incorporate a millimeter wave back-up, which would not be affected by the same heavy, visibility-limiting weather. Combining radio and laser (or LED transmitter) in tandem works particularly well. This explains because millimeter wave transmission is affected more by rain (because the carrier wavelength is closer to the size of a rain drop) and optical transmission is affected more by fog. Rain drops can vary in size from 0.1mm to 10,0mm, and these will effectively disperse millimeter waves, especially with carrier frequencies greater than 10 GHz (10 GHz = 30, 0 mm wavelength; 38 GHz = 8, 0 mm wavelength). Fog is typically 1 to 20 micron, and will effectively scatter the FSO wavelengths of 0.785 -0.85 and 1.55 micron. The only weather that could affect the transmission of a hybrid FSO/RF is conditions of simultaneous heavy rain and thick fog. Luckily, these conditions would not occur simultaneously, because as the rain falls, the rain droplets would absorb the suspended fog water droplets, thus diminishing the fog.

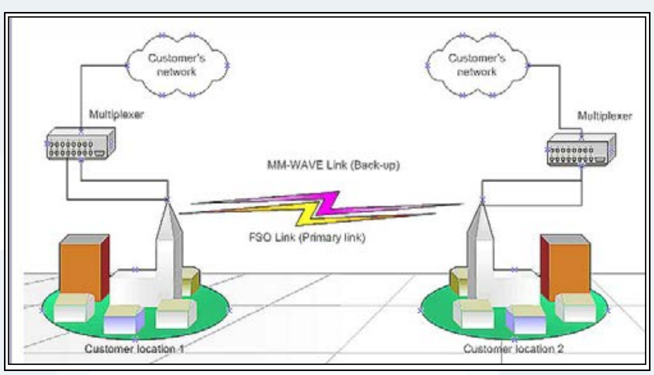

Fig.5: FSO hot-swap back-up by mm-wave link. Redundant paths and failover capability are using a third-party multiplexer on both sides of the link.

A real advantage of mm-wave links as FSO back-up is that they have to back-up them at relatively short distances because of FSO nature. Based on FSO technical specs and installation statistics, most of the FSO links are installed on distances no more than 1km, while mm-wave links are designed to work on distances up to 20km. This means that mm-wave links have the very significant gain margin which allows to penetrate 1km distance even at very heavy rain. According to "Rain Attenuation" chart that are available at page 13 of FCC Bulletin 70 (see link below), the maximum attenuation for frequencies 40-100GHz is 50dB/km that much less than max thick fog attenuation of 350dB/km [5].

III. Future considerations

FSO is just starting to be applied to solve the Internet "last-mile" interconnectivity problem. Some believe that it may be the unlimited bandwidth solution for the metro urban core of downtown building to-building communication, as well as the optimal technology for home-to-home and office-to-office connectivity. FSO systems have been shown to be reliable (99.9% to 99.999%) communication channels with fast bandwidth. They are easy to set up and provide cost-effective solutions. The industry, however, does not yet know how to properly deploy them in telecom networks. To address these concerns, the FSO community recently launched the Free Space Optics Alliance to educate the communication industry as a whole. It is believed that industry-wide education will enable standards to emerge and growth of FSO technology to occur. Finally, it should be noted that to better quantify the technical and scientific aspects of FSO, there is still a need for research in new laser sources, atmospheric spectroscopy, multibeam and active alignment techniques and multidetector averaging.

IV. Conclusion

The main problems in today's last mile solutions that are based on microwave communication technology are bandwidth limitations and security. FSO however offers solutions for all of these problems. Free Space Optics (FSO) is an optical technology that offers high-speed last-mile solution and has capabilities to be used for Quantum Key Distribution. FSO requires no licensing or frequency synchronization. It allows transmission of data with, theoretically "unlimited" bandwidth and thus represents a viable solution for the last-mile problem. FSO is also capable of providing secure communication of quantum keys, since, by nature, optical channel is very hard to intercept, but even if interception took place it can be easily detected due to photon misalignment. On the other hand, carrier-class link quality for FSO is much harder to achieve, mainly due to FSO's dependence on uncontrollable factors like weather and scintillation.

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