Link Margin Optimization of Free Space Optical Link under the Impact of Varying Meteorological Conditions

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Abstract
FSO is a free space optical technology synonymous to optical wireless communication and often called as open-air photonics or infrared broadband. In free space optical communication, data is transmitted from point-to-point and multipoint using low-powered infrared lasers. FSO allows transmitting and receiving of voice, video, and data information. High speed and license free installation are the key features of this technology. The performance of FSO link is significantly affected by meteorological conditions viz. rain, scintillation, geometric attenuation and snow etc. In this paper we have formulated the link margin equation for the performance evaluation of FSO link under varying meteorological conditions. Performance of the considered FSO link has been optimized on the basis of signal wavelength, link length and launched power level.

Keywords: FSO, Link Margin, Attenuation, Scintillation

1. Introduction

Abbreviated as FSO, free space optics technology is also referred to as open-air photonics or optical wireless or infrared broadband which transmits data from point-to-point and multipoint using low-powered infrared lasers. The rising demand of high bandwidth transmission links for the next generation access networks that provide security and ease in installation has led to the interest in free space optics (FSO). FSO link provides highest data rates due to their high carrier frequency in the range of 300 THz. FSO is license free and offers low bit error rate that is required for a carrier grade access technology [1]. Free-space optical wireless is the concept of sending very high bandwidth information data from one point to the other using optical beam. Optical wireless uses light sources and detectors to send and receive the information between the transceiver nodes through the atmospheric free-space channel. Optical wireless can be a preferred access technology in next generation access networks for its number of prime advantages over radio frequency (RF) links, like secure and license-free band of operation, relatively high bandwidth, dense spatial reuse, no issues like electromagnetic compatibility (EMC) and electromagnetic interference (EMI), and low power usage per transmitted bit. The principal requirement of a fully functional optical wireless link is clear line of sight (LoS) and the precise alignment between communicating nodes [2]. Currently FSO is being researched for applications involving ground-to-ground (short and long distance terrestrial links), satellite uplink/downlink, inter-satellite, deep space probes to ground, and ground-to-air/air-to-ground terminal. This has resulted in some successful experiments such as SILEX (a link between Artemis and SPOT-4). The prime advantages of FSO are: higher data rates exceeding easily 100 bit/s using wavelength division multiplexing (WDM) techniques, security aspects, EMC/EMI immunity and frequency regulation issues [3].The availability performance of FSO links is significantly limited by the propagation conditions in the atmosphere. It appears that electromagnetic waves in the optical region are strongly attenuated in the direction of optical beam propagation by scattering and absorption processes in the atmosphere. Fog events and strong snow events are the most adverse weather conditions because they result in a high specific attenuation of optical waves. Since the fade margin of current FSO systems reaches a maximum of several tenths of a dB (eye safety requirements), the systems can easily become unavailable when communication is interrupted. It follows that the higher the occurrence rate of such adverse propagation conditions, the lower the availability time of the system that can be reached [4]. Light propagation is very sensitive to atmospheric conditions and meteorological effects, such as haze, fog, drizzle, rain, turbulence and thermal expansion of structures, all of them fading the received signal more than radio waves. Because of the attraction of the powerful advantages, much effort has been made seeking to overcome the limitations imposed by the channel conditions [5].The atmospheric channel conditions such as scattering and absorption mainly cause power loss in the received signal. For optical links covering a few hundred meters or more distances, atmospheric turbulence can cause severe error rates due to the random fluctuations in the received signal [6]. Intensity fluctuation, commonly called scintillation, is generally considered to be a fundamental limiting factor in the performance of free space optical (FSO) communication. A lot of works have been done in investigating the influence of scintillation over FSO links and most of this literature is limited to Rytov based scintillation model. Although this model has been proved to be valid for most scenarios, it is not applicable for long-distance links, especially in the case of strong fluctuation conditions. This is mainly due to the fact that the conventional scintillation model does not consider the influence of beam wander on the scintillation [7]. Beam wander is commonly attributed to the presence of large eddies in the atmospheric turbulence structure which causes some degree of refraction in the entire optical beam that crossed them, deviating from its original path. Beam wander is negligible for a near-field path, while for long-distance path, it should be taken into account because it can be large enough to cause severe performance degradation of FSO links. The effects of beam wander on the system performance of FSO links have been investigated in [8], [9]. In terrestrial applications, the FSO systems are most frequently used as a last-mile telecommunications link or as a LAN link between buildings. For telecommunication (carrier-class) applications, the link availability is generally considered to be 99.999 % while for the LAN applications (enterprise-class) a link availability of over 99 % is usually sufficient [10].

2. System Parameters

The parameters can be divided into two categories which are predictable attenuations and unpredictable attenuations. Predictable attenuations are geometrical attenuation and molecular attenuation. While unpredictable attenuations are atmospheric attenuation, rain attenuation, and scintillation [11].

2.1 Geometric Attenuation

Geometrical attenuation is predictable attenuation .Geometrical attenuation is a fixed value for a specific FSO system since it does not vary with time. Geometrical attenuation occurred when the light beam is diverged as it moves throughout its propagation path. As a result not the entire light beam hits the receiver. Geometrical attenuation is given by the formula:

$$Att_{geo} = \frac{S_d}{S_{capture}} = \frac{\frac{\pi}{4}(d\theta)^2}{S_{capture}} \tag{1}$$

Where S_d is spot surface at distance d, θ is beam divergence, d is the distance between transmitter and receiver and $S_{capture}$ is the capture area of the receiver.

ATMOSPERIC ATTENUATION

Atmospheric attenuation is unpredictable attenuation. The additive effect of absorption and scattering of the infrared light by gas molecules and aerosols present in the atmosphere is the cause of atmospheric attenuation. Atmospheric attenuation can be expressed as follows:

$$\alpha = e^{-\sigma l} \tag{2}$$

l - is distance at which measurement occurred.
σ - is the specific attenuation coefficient per unit of length.

To calculate the value of σ the following relation is used:

$$\sigma \cong \frac{3.912}{v}\left(\left(\frac{\lambda}{550}\right)^{-q}\right) \tag{3}$$

Here, v - is the visibility(km).
λ - is the wavelength(nm).
q- is the size distribution of diffusing particles.

RAIN ATTENUATION

Rain attenuation is unpredictable attenuation. Rain is expected to be the major impairment to FSO link availability. Attenuation of the rain is independent of the wavelength. It is in a function of precipitation intensity R (mm/hr) and is given by the carbonneau relation as follows:

$$Att_{rain} = 1.076 * R^{\frac{2}{3}} \tag{4}$$

SCINTILLATION

Scintillation attenuation is unpredictable attenuation. Scintillation is best defined as the temporal and spatial variations in light intensity caused by atmospheric turbulence. Such turbulence is caused by wind and temperature gradients that create pockets of air with rapidly varying densities and therefore fast-changing indices of optical refraction. The signal attenuation caused by scintillation effect depends on the time of day and can vary orders of magnitude during a hot day. So scintillation is a random, rapid fluctuation in light intensity at the receiver. It is occurs during a hot, sunny day, when the sun heats up the ground and the surrounding air. It will make the convection current rising up and cause air pocket to move about in a turbulent manner. Some air pockets heat up more than others and it behave like lenses, focusing and defocusing the laser beam as it passes through the atmosphere. Scintillation attenuation can be expressed as follows:

$$\sigma_{scin} = \left|10 \log\left(1 - \sqrt{\sigma_{\mathrm{scin}}^2}\right)\right| \tag{5}$$

Where σ_{scin}^2 is scintillation index and can be determined by the following relation:

$$\sigma_{scin}^2 = 2 * \sqrt{23.17 \left(\frac{2\pi}{\lambda} 10^9\right)^{\frac{7}{6}} * C_2^n * L^{\frac{11}{6}}} \tag{6}$$

λ is wavelength(nm).

C_2^n is refractive index structure parameter(m).

L is link length(m).

C_2^n is taken as

$$C_2^n = \begin{cases} 10^{-16} & \text{for low turbulance} \\ 10^{-14} & \text{for moderate turbulance} \\ 10^{-13} & \text{for high turbulance} \end{cases}$$

SNOW ATTENUATION

Attenuation due to snow is a function of the wavelength (nm) and precipitation intensity S (mm/h) .Snow intensity S is the fundamental parameter used to locally describe the snow. Its measurement is carried out in meteorological station. Characteristics of snow precipitation are derived from those of rain precipitation in function of system altitude. A weighting coefficient, function of altitude (km), is applied to rain rainfall rate, Rp, exceeded for any given percentage p of the average year for any location. Knowing the link margin deduced from the optical power link budget, we can deduce, by dichotomy, the interruption probability of the link due to snow.

Wet snow (altitude < 500m): $Att_{snow} = (0.0001023 * \lambda_{nm} + 3.7855466) * S^{0.72}(dB/km)$

Dry snow (altitude > or =500m): $Att_{snow} = (0.0000542 * \lambda_{nm} + 5.4958776) * S^{1.38}(dB/km)$

LINK MARGIN EQUATION

Link margin also called as fade margin is the percentage of time that the link is operating satisfactorily and when the link margin is not exceeded is known as link availability. Taking above meteorological conditions into account link margin equation has been formulated as under:

$$Link\ margin(dB) = P_e + |S_r| - Att_{geo}(dB) - Att_{att}(dB) - Att_{rain}(dB) - Att_{scin}(dB) - Att_{snow}(dB).$$

Where,

P_e - is total power of the emitter (dBm),

$|S_r|$ - is sensitivity of the receiver (dBm),

Att_{geo} - is geometrical attenuation (dB),

Att_{atm} - is atmospheric attenuation (dB),

Att_{rain} - is rain attenuation (dB),

Att_{scin} - is scintillation attenuation (dB),

Att_{snow} - is snow attenuation (dB),

RESULTS AND DISCUSSIONS

Scenario1: Hot summer conditions.

Fig.1 (a-c) shows the dependence of link margin of free space optics link on the link length at central wavelength of 850 nm, 1300 nm and 1500 nm respectively. It is evident from plots that link margin remains more than five initially upto 2km to 3km in all the above cases and then droops gradually after and small surge around 4km length.

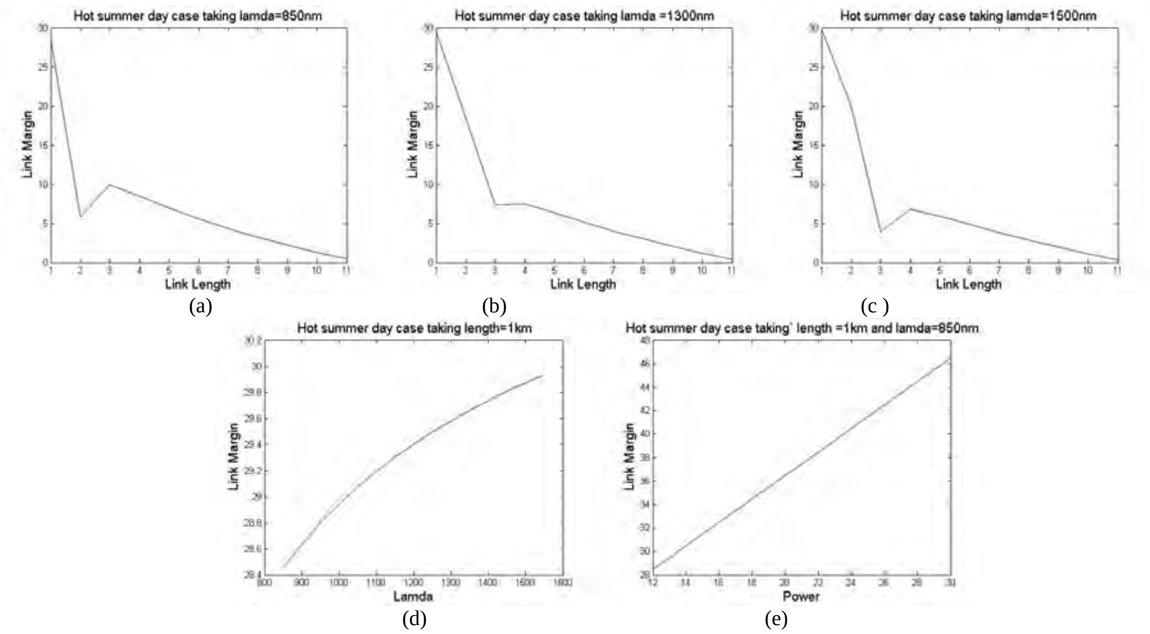

Fig1. Hot summer conditions: (a)Link Margin v/s Link Length at λ=850 nm, (b)Link Margin v/s Link Length at λ=1300 nm, (c)Link Margin v/s Link Length at λ=1500 nm, (d)Link Margin v/s λ at 1km length, (e)Link Margin v/s Power at λ=850 nm with 1km length.

Fig.1(d) shows that in case of hot conditions, link margin increases with increase in wavelength(λ) and linear increase in link margin has been observed with increase in power as shown in Fig.1(e)

Scenario II : Rainy conditions.

Fig.2 (a-c) shows the variance of link margin of free space optics link with the link length at central wavelength of 850 nm, 1300 nm and 1500 nm respectively. It is evident from plots that link margin decreases gradually as the link length increases.

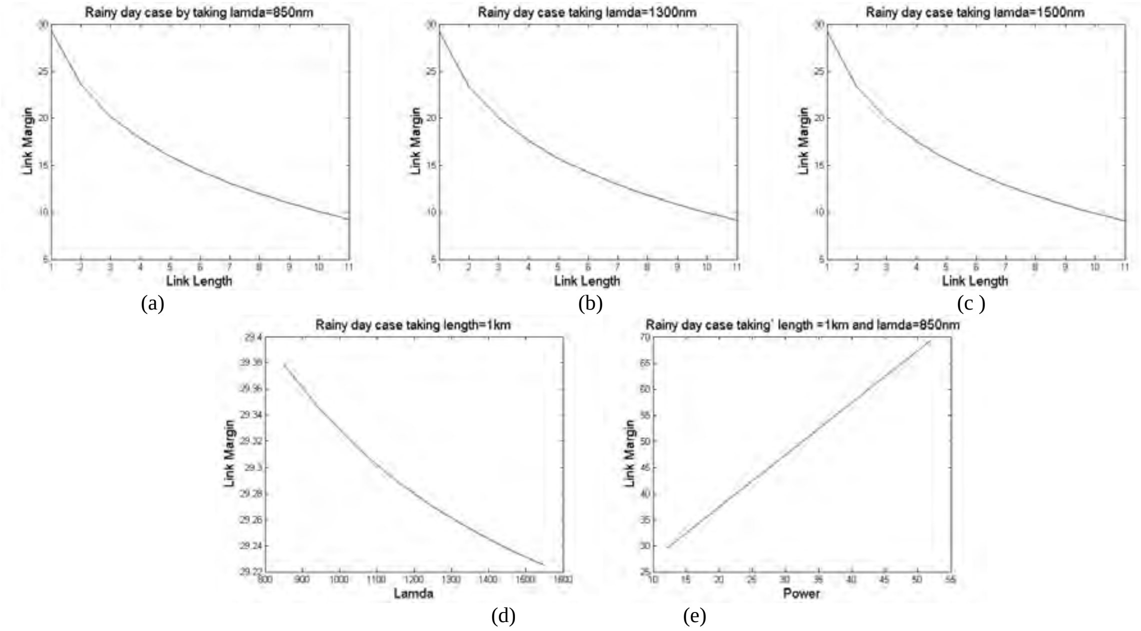

Fig2. Rainy conditions: (a)Link Margin v/s Link Length at λ=850 nm, (b)Link Margin v/s Link Length at λ=1300 nm, (c)Link Margin v/s Link Length at λ=1500 nm, (d)Link Margin v/s λ at 1km length, (e)Link Margin v/s Power at λ=850 nm with 1km length.

Fig.2 (d) shows that in case of rainy conditions, link margin decreases with increase in wavelength (λ) and it increases linearly with increase in power (Fig.2e).

Scenario III: Winter conditions.

Fig.3 (a-c) shows the dependence of link margin of free space optics link on the link length at central wavelength of 850 nm, 1300 nm and 1500 nm respectively. It is evident from plots that link margin decreases gradually as the link length increases.

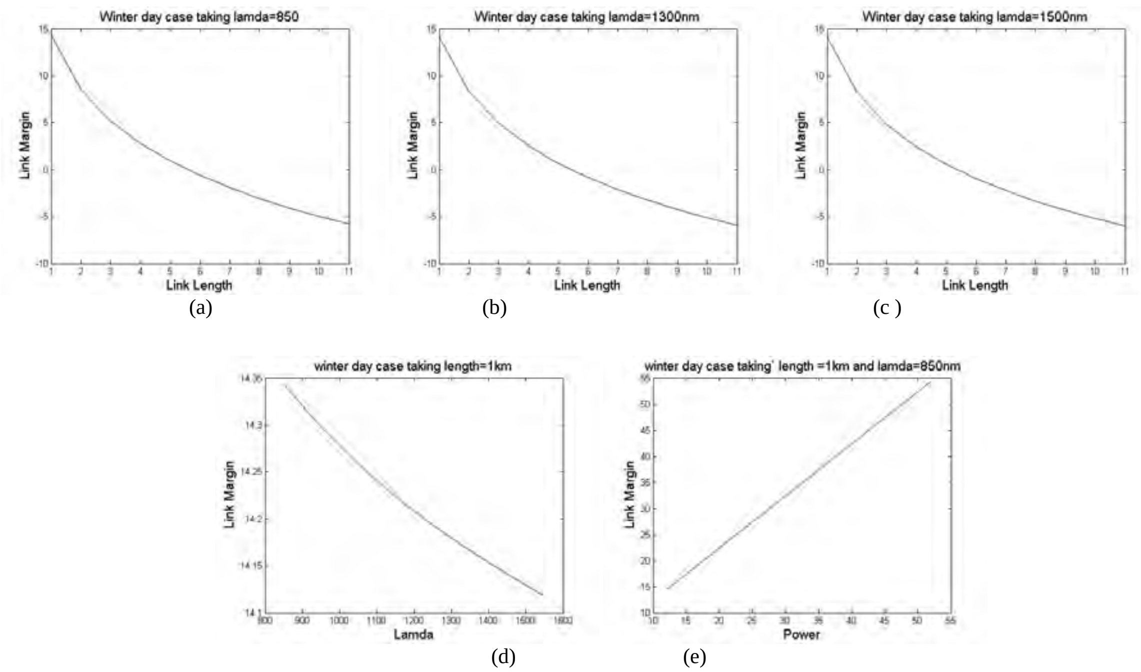

Fig3.winter conditions: (a)Link Margin v/s Link Length at λ=850 nm, (b)Link Margin v/s Link Length at λ=1300 nm, (c)Link Margin v/s Link Length at λ=1500 nm, (d)Link Margin v/s λ at 1km length, (e)Link Margin v/s Power at λ=850 nm with 1km length.

Fig.3 (d) shows that in case of rainy conditions, link margin decreases with increase in wavelength (λ) and linear increase in link margin has been observed with increase in power as shown in Fig.3 (e).

CONCLUSION

In this paper link margin equation has been formulated for performance evaluation of free space optics link under varying meteorological conditions. Performance of proposed FSO link has been gauged on the basis of signal wavelength, link length and launched power level. Link margin reported is more than 5 under all considered conditions upto 2km. Highest cumulative link margin of 73.19 has been observed at 1500 nm as compared to 850 nm and 1300 nm. Robustness of this system is thus confirmed for link length upto 2km at λ=1500nm.

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