Performance of a FSO Link in Presence of Cloud

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Abstract— Over conventional microwave and optical fiber communication systems, Free Space Optical (FSO) communication links have some distinct advantages by virtue of their high carrier frequencies. However, a number of limitations caused by atmospheric phenomena like cloud, fog, aerosols even turbulence makes it difficult to achieve the desired level of performance. In this article, we investigate the bit error rate performance of intensity modulated FSO with direct detection (IM/DD) in single-input single-output (SISO) for the perfect inter symbol interference (ISI) caused by beam broadening at the receiver due to the effect of cloud, assuming that a single information-bearing signal is transmitted.

Keywords— BER, FSO, IM/DD, ISI, SISO

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1 INTRODUCTION

THE huge amount of data exchange between satellites and ground stations demands enormous capacity that cannot be provided by strictly regulated, scarce resources of the Radio Frequency (RF) spectrum [1]. On the other hand Free Space Optical (FSO) communications has the potential of providing enormous bandwidth. In addition, FSO links are difficult to intercept, immune to interference or jamming from external sources, and because of spatial confinement of laser beams significantly reduces the power loss [2, 3]. All these benefits are viable only under ideal channel conditions. But the atmosphere has a detrimental effect on a propagating laser beam which is the main drawback of a FSO link. Various atmospheric phenomena such as clouds, fog, aerosols, and even turbulence can severely degrade the performance by not only scattering the laser beam, giving rise to optical pulse attenuation and broadening in space and times but also disruptions in the amplitude and phase of received signal [4,5]. The broadening of the received optical pulse in space and time causes Inter symbol interference (ISI). The performance of IM/DD FSO systems for different turbulence models has been well studied in the literature. Maximum likelihood sequence detection (MLSD) for IM/DD FSO links was employed by the study of Zhu and Kahn [6]. They continued their study to find out the pairwise error probability of coded FSO links assuming the log-normal distributed turbulence model [7]. A further study of the pairwise error probability for on-off keying (OOK) with temporally correlated *K*-distributed turbulence was carried out by Uysal *et al* in [8].In [3], Ehsan Bayaki et al, find out the pairwise error probability of MIMO FSO link for on-off keying (OOK) with Gamma -Gamma distribution because of its excellent correlation with the measured data for a wide range of turbulence condition (weak to strong) as the log-normal distribution is used for weak turbulence. Pointing errors can affect the FSO system performance since FSO communications requires LOS links. In [9], Farid and Hranilovic presented an FSO channel model considering the effect of fading due to log-normal/Gamma-Gamma atmospheric turbulence and pointing errors by considering beam width, pointing error variance and detector size. The BER of a SISO FSO link impaired by *K*-fading (a special case of Gamma-Gamma fading) and pointing error was expressed in terms of the Meijer's G–function in [10].Later on, this approach has also been extended to MIMO FSO links [11]. Later, Uysal extended their discussion of pair wise error probability for coded OOK FSO links to the cases with independent Gamma-Gamma turbulence [12]. Another new approach, a multiple symbol detection decision metric for OOK in both log-normal and Gamma-Gamma turbulence was investigated by Riediger *et al. in* [13]. Vavoulas et al. demonstrated the design for robust FSO link for various weather conditions, cases like snow, fog and rain [14]. But In this paper, the effect of inter symbol interference caused by cloud is investigated for a SISO free space optical (FSO) communication scheme.

2 SYSTEM MODEL

Basing upon Monte Carlo simulations mathematical models are developed for the temporal characteristics of optical pulse propagation through clouds. These include temporal impulse response, transfer function, bandwidth, received energy and board analysis. The simulation results strongly supports the use of double gamma function model to best describe optical pulse spread through clouds [15]. A FSO link is normally consists of a transmitter, a channel which would be the medium of transmission and it would be atmospheric that includes cloud and finally a receiver to reproduce that transmitted signal. The block diagram is shown in Figure 1.

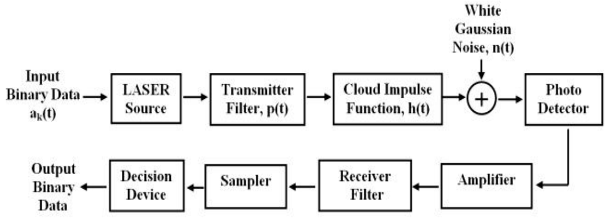

Figure 1: Basic FSO system model

Most practical wireless optical channels use light emitting diodes or laser diodes as transmitters and photodiodes as detectors as shown above. These device modulate and detect solely the intensity of carriers not its phase which implies that all transmitted signal intensities are non-negative.
The input binary data is used to modulate the laser using intensity modulation and thus pass through the transmitted filter and then it passes through the atmosphere where the impulse response has a greater impact. The optical signal is detected by a photo detector and received by the receiver circuit. The sampler and decision device is used to determine the output binary data.

2.1 Intensity Modulated Direct Detection (IM/DD)

When the optical power output of a source is varied in accordance with some characteristics of the modulating signal then this modulation from is named as intensity modulation and in the receiver side direct detection technique is used for the regeneration of the modulating signal.

2.2 Cumulus Cloud Model and Gamma Constant

Cumulus clouds are generally located at the height of 200 and 20000 feet over the ground. This elevation range is very relevant for space communications involving planes. Low lever stratus clouds are usually between 1000 and 2000 feet elevation and as such are unsuitable for aircraft communications. Since particulate scatter close to receiver is of more serious consequences than scatter far away from it. Therefore we will concentrate our study on cumulus clouds.

3 PERFORMANCE ANALYSIS

In this section we present mathematical analysis of BER of SISO (Single-Input Single-output) FSO link for Intensity Modulation – Direct Detection (IM / DD). For the perfor mance analysis of the FSO link signal we have considered some parameters that are listed below-

TABLE 1
DOUBLE GAMMA FUNCTION CONSTANTS: CLOUD THICKNESS OF 200 M [15]

Gamma Function Constant	Wavelengths		
	0.532 μm	0.8 μm	1.3 μm
k_1	120.1	62.4	16.5
k_2	1.9×10^7	1.8×10^7	1.1×10^7
k_3	1.55	2.9	0.67
k_4	3×10^6	3.5×10^6	2.13×10^6

Optical radiation propagating through clouds experiences temporal distortions. A function that describes well the temporal impulse response is the double gamma function [15]-

TABLE 2
DOUBLE GAMMA FUNCTION CONSTANTS: CLOUD THICKNESS OF 200 M [15]

Gamma Function Constant	Wavelengths		
	0.532 μm	0.8 μm	1.3 μm
k_1	12.4	5.2	2
k_2	1.1×10^7	0.8×10^7	0.71×10^7
k_3	0.66	0.41	0.3
k_4	2.4×10^6	1.9×10^6	1.8×10^6

$$h(t) = \{k_1(c_1)te^{-[k_2(c_1)]t} + k_3(c_1)te^{-[k_4(c_1)]t}\}U(t) \quad (1)$$

Where, h (t) is in m^{-2}, c_1 is a parameter defining the physical characteristics of the optical channel such as particulate size distribution, particulate refractive index, geometrical cloud thickness and radiation wavelengths, and k_1-k_4 are the gamma function constants depending on c_1 and U (t) is a unit step function. The temporal frequency transfer function can be evaluated by Fourier transforming the temporal impulse response [15]

$$H(f) = \int_{-\infty}^{\infty} h(t)e^{-(j2\pi ft)}d(t) \quad (2)$$

Where, f is the temporal frequency (Hz). Substituting (1) into (2) yields-

$$H(f) = \{\frac{k_1(c_1)}{[k_2(c_1 + j2\pi f)]^2} + \frac{k_3(c_1)}{[k_4(c_1 + j2\pi f)]^2}\} \quad (3)$$

$$H(f)=G\left\{\left[1+j\left(\frac{f-b}{f_3}\right)\right]\left[1+j\left(\frac{f+b}{f_3}\right)\right]\right\}\Big/\left\{\left[1+j\left(\frac{f}{f_3}\right)\right]^2\left[1+j\left(\frac{f}{f_2}\right)\right]^2\right\} \quad (4)$$

For a given set of parameters [15]- The transmitted optical signal is given by

$f_1=\frac{k_2}{2\pi}$	$f_2=\frac{k_4}{2\pi}$	$f_2=\frac{(k_1k_4+k_3k_2)}{2\pi(k_1+k_3)}$
$G=\frac{4\pi^2(k_1+k_3)}{(k_2k_4)^2}{k_3}^2$	$b=\frac{4\pi^2(k_1+k_3)}{(k_2k_4)^2}{f_3}^2$	

Where, p_T is the transmitted optical power, a_k is the k-th

$$s(t)=\sqrt{2pr}\sum_{k=-\alpha}^{\alpha}a_k\,p(t-kT_b)e^{(jw_ct)} \quad (5)$$

information bit whose value is 1 and 0, p (t) is the optical pulse shape of bit duration T_b and carrier frequency of fc.

The received optical signal is given by

$$r(t)=\sqrt{2p_s}\sum_{k=-\alpha}^{\alpha}a_k\,p(t-kT_b)e^{(jw_ct)} \quad (6)$$

where, P_s is the received optical power and g (t) = h (t)$\otimes$p(t) is the received optical pulse shape which overlaps over a number of bits and produce Inter Symbol Interference (ISI) .

$$\begin{aligned} i(t)&=|r(t)|^2R_d \\ &=2R_dP_S\left|\sum_{k=-\infty}^{\infty}a_kg(t-kT_b)\right|^2+i_n(t) \end{aligned} \quad (7)$$

The photo current can be expressed as –
where, R_d is the responsivity of the detector and $i_n(t)$ is the noise current due to photo diode and receiver noise current which can be expressed as [17]

$$i_n(t)=i_{sh}(t)+i_{th}(t) \quad (8)$$

SINR can be defined as the ratio of signal power to noise power plus interference power, i.e.

$$SINR=\frac{SignalPower}{NoisePower+InterferencePower}=\left[\frac{{i_s}^2}{{\sigma_n}^2+\sigma isi^2}\right] \quad (9)$$

$$i_s(t)=2R_dP_S|a_0|^2.|g(t)|^2$$

Mean Signal Current,

$$I_s(t)=\overline{i_s(t)^2}=2R_dp_s\frac{1}{T_b}\int_0^{T_b}|g(t)|^2dt$$

Mean ISI Current,

$$\sigma_{isi}(t)=\overline{\sigma_{isi}(t)^2}=2R_dp_s\frac{1}{T_b}\int_0^{T_b}|a_kg(t-kT_b)|^2dt$$

Where,
Noise Power, $\sigma_n^2=\sigma_{shot}^2+\sigma_{th}^2$
Shot Noise Power, $\sigma_{shot}^2=2eBIs$
Thermal Noise Power, $\sigma_{th}^2=4KTB/R_L$

B= Signal Bandwidth (Hz), R_L= Load Resistance
K= Boltzmann Constant, T= Ambient Temperature

The expression of BER for Intensity Modulation Direct Detection (IM/DD) can be expressed as [16]

$$BER=0.5erfc\left(\frac{\sqrt{SINR}}{2\sqrt{2}}\right) \quad (10)$$

3 RESULTS AND DISCUSSIONS

In this section we compare the BER performance of SISO optical communication system in presence of cloud. We present the numerical results of BER of the FSO link considering the effect of cloud and without could. We make the theoretical analysis of the system for the given set of Gama function constant for different wavelengths mentioned in Table 1 and Table 2. We used MATLAB tools for this simulation. Figure 2, demonstrates the received optical pulse shape for different carrier wavelength for a transmission bandwidth of 1GHz. It shows that the broadening of the optical pulses arriving at the receiver due to the scattering cloud. This broadening of pulse causes inter-symbol interference (ISI) at the receiver.

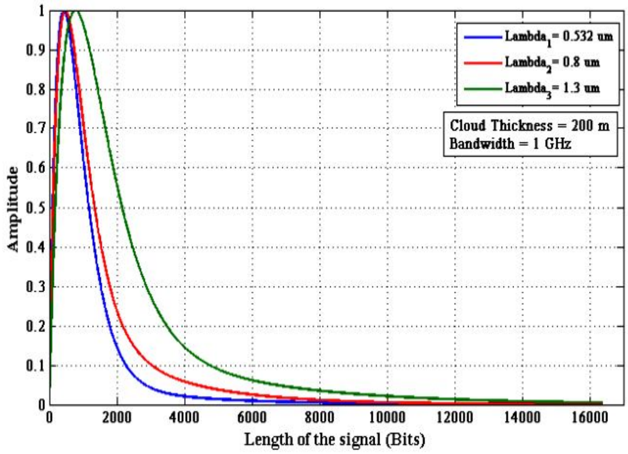

Figure 2: Received optical pulse shape

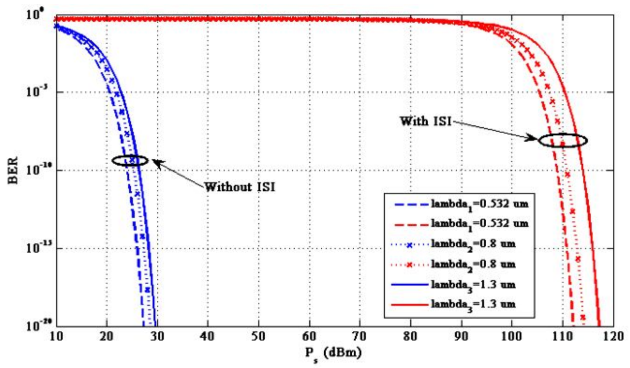

Figure 3: BER performance of a FSO link with ISI and without ISI for different wavelengths by taking the cloud thickness as 200 m (for the parameters listed in Table 1)

In Figure 3, we present the graphical representation of BER vs. received power in dBm considering the effect of ISI and without ISI. It shows that there exists a significant variation in received power due to the effect of cloud for all optical carrier wavelengths. The received power without the inter symbol interference is around 25-30 dBm, whereas the required received power to overcome the inter symbol interference for maintaining a specific bit error 10^{-10} is 105-110 dBm. This value is unrealistic. It shows unrealistic values of power required for transmission in the presence of cloud.

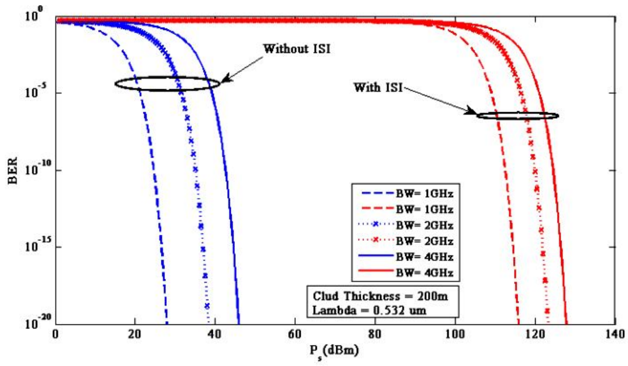

Figure 4: BER performance of a FSO link with ISI and without ISI for different wavelengths by taking the cloud thickness as 250 m (for the parameters listed in Table 2)

In Fig. 4, we demonstrate the effect of cloud for all carrier wavelengths considering the transmission bandwidth of 1GHz for the parameters listed in Table II. For further investigation we varied the transmission bandwidth for different carrier wavelength communication. Fig. 5, 6, and 7 illustrates the BER performance of a SISO link for various bandwidths.

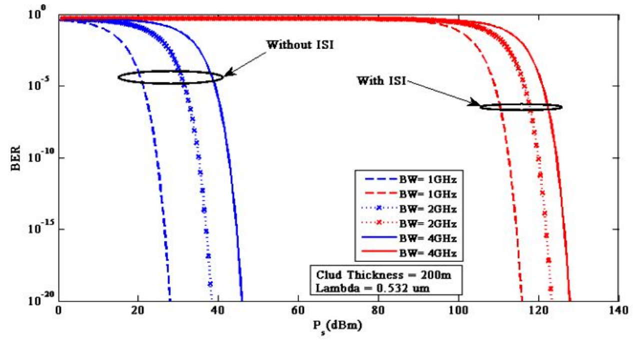

Figure 5: BER performance of a FSO link with ISI and without ISI for different Bandwidths for λ=0.532μm (for the parameters listed in Table 1)

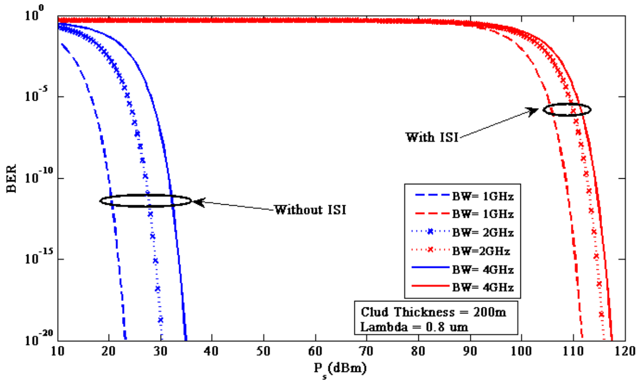

Figure 6: BER performance of a FSO link with ISI and without ISI for different Bandwidths for λ=0.8μm (for the parameters listed in Table 1)

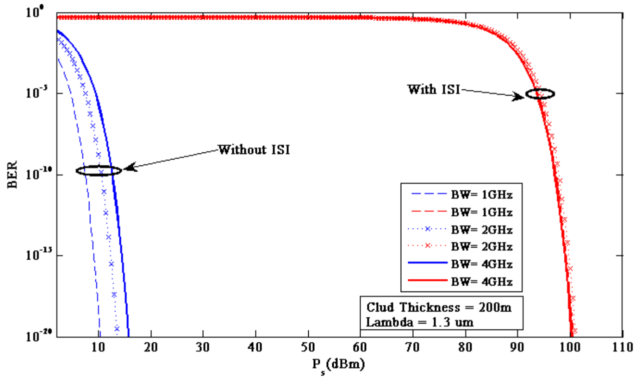

Figure 7: BER performance of a FSO link with ISI and without ISI for different Bandwidths for λ=1.3μm (for the parameters listed in Table 1)

The whole performance of the optical system can be quantified in terms of power penalty for better understanding. The power penalty is defined as the increase of optical power required to overcome a given effects with respect to an ideal system.

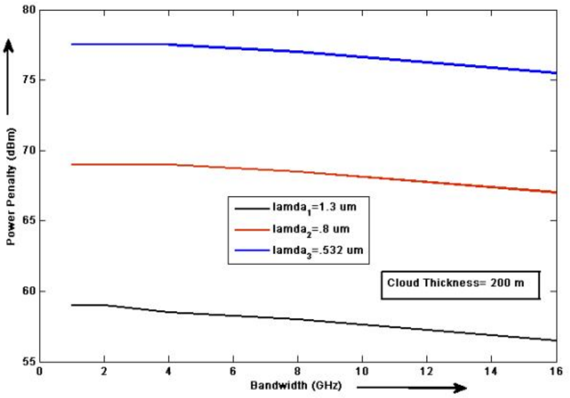

Figure 8: Relation between Power Penalty and Bandwidths for different wavelengths by taking the cloud thickness as 200 m (for the parameters listed in Table 1)

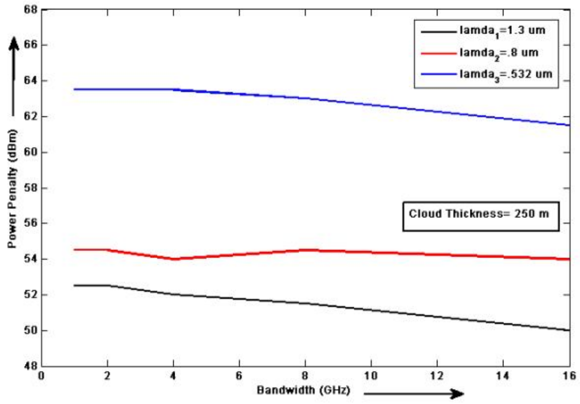

Figure 9: Relation between Power Penalty and Bandwidths for different wavelengths by taking the cloud thickness as 250 m (for the parameters listed in Table 2)

Fig. 8 and Fig. 9 shows the required optical power in dBm for various transmission bandwidths for maintaining a bit error rate (BER) of 10^{-10}.From Fig. 8, the required optical power (for the cloud thickness of 200 m) to overcome the inter symbol interference varies about 55 dBm to 59 dBm for a wide range of transmission bit rate (1Gb/s-16 Gb/s) for the carrier wavelength of λ=1.3 μm. While the required optical power for the wavelength of λ=0.8 μm is about 67 dBm to 69 dBm. Whereas for λ=0.532 μm the value is about 74 dBm to 78 dBm for the same bit rate. In Figure 9, the required optical power (for the cloud thickness of 250 m) to overcome the inter symbol interference varies about 50 dBm to 53 dBm for a wide range of transmission bit rate (1Gb/s-16 Gb/s) for the carrier wavelength of λ=1.3 μm. While the required optical power for the wavelength of λ=0.8 μm is about 54 dBm to 55 dBm. Whereas for λ=0.532 μm the value is about 60 dBm to 65 dBm for the same bit rate.

4. Conclusion

In this paper, we have presented a very basic approach to performance analysis of SISO free space optical systems (FSO) considering the effect of cloud. The proposed technique is based on finding the noise power caused by inter symbol interference (ISI) from the received pulse shape by using MATLAB tools for a single bit transmission. Then we investigated the BER performances for various optical wavelength communications by varying transmission bit rate. Then we also quantified the performance of the link in terms power penalty. It is found for SISO free space optical link, for any transmission bit rate under the effect of cloud thickness of 200 m and 250 m, the required received power value is unrealistic (more than 100 dBm) which suggest no communication is possible using this modulation scheme. This area badly needs an experimental research demonstration for possibilities of communication as FSO link is very important issue for future optical networking. Further research can be carried to overcome this problem. There is ample scope to conduct more detail research in this field for a concrete decision and subsequent remedy.

References

[1] Ivan B. Djordjevic, Bane Vasic and Mark A. Neifield, "Multilevel Coding in Free-Space Optical MIMO Transmission with Q-ary PPM Over the Atmospheric Turbulence Channel, IEEE Photonics Technology Letter, Vol. 18, No. 14, (2006).

[2] Zeinab Hajjarian and Jarir Fadlullah, Mohsen Kavehrad, MIMO Free Space Optical Communications in Turbid and Turbulent Atmosphere(Invited Paper),The Pennsylvania State University Department of Electrical Engineering, University Park, PA. 16802, USA.

[3] Ehsan Bayaki, Robert Schober, and Ranjan K.Mallick, Performance Analysis of Free–Space Optical Systems in Gamma–Gamma Fading, IEEE Global Communications Conference (Globecom), New Orleans, Dec. (2008).

[4] Hanling Wu, Haixing Yan, Xinyang Li, "Performance analysis of bit error rate for free space optical communication with tip-tilt compensation based on gamma–gamma distribution," Optica Applicata, Vol. 39, No. 3, (2009).

[5] S. Mohammad Navidpour and Mohsen Kaverhrad, "BER Performance of Free Space optical Transmission with Spatial Diversity," IEEE Transactions on Wireless Communications. Vol. 6, No. 08, (2007).

[6] Zhu X, Kahn J M, "Free-space optical communication through atmospheric turbulence channels," IEEE Trans. Commun. 50(8): (2002)1293-1300.

[7] Zhu X, Kahn J M, "Performance bounds for coded free-space optical communications through atmospheric turbulence channels," IEEE Trans. Commun. 51(8): (2003)1233-1239.

[8] Uysal M, Navidpour S M, Li J, "Error rate performance of coded free-space optical links over strong turbulence channels," IEEE Commun. Lett. 8(10): (2004) 635-637.

[9] Farid A A, Hranilovic S "Outage capacity optimization for free-space optical links with pointing errors, IEEE/OSA J. Light wave Technol. 25(7): (2007)1702-1710.

[10] Sandalidis H G, Tsiftsis T A, Karagiannidis G K, Uysal M, "BER performance of FSO links over strong atmospheric turbulence channels with pointing errors," IEEE Commun.Lett. 12(1): (2008) 44-46.

[11] T. A. Tsiftsis, H. G. Sandalidis, G. K. Karagiannidis, and M. Uysal, "FSO links with spatial diversity over strong atmos-

pheric turbulence channels," in Proc. IEEE Intern. Conf. Commun. (ICC), (2008) pp. 5379–5384.

[12] Uysal M,Li J, Yu M, "Error rate performance analysis of coded free-space optical links over Gamma-Gamma atmospheric turbulence channels," IEEE Trans. Wireless Commun. 5(6): (2006) 1229-1233.

[13] Riediger ML B, Schober R, Lampe L, "Fast multiple-symbol detection for free-space optical communications," IEEE Trans. Wireless Commun. 57(4) (2009) 1119-1128.

[14] Alexander Vavoulas, Harilaos G. Sandalidis, and Dimitris Varoutas, "Weather Effects on FSO Network Connectivity" J. OPT. COMMUN. NETW./VOL. 4, NO. 10/OCTOBER 2012

[15] S. Arnon, D. Sadot and N.S. Kopeika, "Analysis of Optical Pulse Distortion through Clouds for Satellite to Earth Adaptive Optical Communication, Journal of Modern Optics," Vol. 41, No. 8, (1994), 1591-1605.

[16] John. M. Senior, "Optical Fibre Communications"- Principles and Practice, 3rd edition, Pearson Education.

[17] Pranjan Das, "Analysis of a Free Space Optical (FSO) Link Under The Influence of Spatial Widening Effect From Propagation Through Clouds", 2011.

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