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Bit Error Rate (BER) Performance of a Free Space Optical (FSO) Link Considering the Effect of Cloud-Induced Fading

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I. Introduction

Current free space optical (FSO) communication systems employ intensity modulation with direct detection (IM/DD) and use point to point communication between two optical transverse along a line of sight [1, 2]. FSO communication is an attractive and license free high bandwidth access and cost-effective solution for high-rate image, voice and data transmission. Despite the major advantages of FSO communications, its widespread use is hampered by several challenges in practical deployment [3, 4]. In literature the performance of IM/DD FSO systems for different turbulence models and pointing errors has been well studied. The pairwise error probability of coded FSO links for the log-normal distributed turbulence model and a turbulence model with temporally correlated K-distributed for on-off keying (OOK) was carried out in [5, 6]. Later, Uysal extended their discussion to find out the pairwise error probability of the FSO links with the cases of independent Gamma-Gamma turbulence for coded on-off OOK keying [7]. For further study Ehsan, Bayaki find out the pairwise error probability of MIMO FSO link with Gamma - Gamma distribution for on-off keying (OOK) because of its excellent correlation with the measured data for a wide range of turbulence condition (weak to strong) in [8]. The FSO system performance can be degraded due to pointing errors since FSO communications requires line of sight (LOS) links. The concept of finding BER of an FSO channel model considering the effect of fading due to log-normal/Gamma-Gamma atmospheric turbulence was first introduced by Farid in [9]. On the same paper they also find out the pointing errors by considering detector size, beam width and pointing error variance. Another special case of Gamma-Gamma fading named K –fading is used to find out the BER and pointing errors of a SISO FSO link in terms of the Meijer G-function in [10]. This approach has also been extended to MIMO FSO links later on[11].Vavoulas et al. find out the design for robust FSO link for various weather condition, cases like snow, fog and rain[12]. For modelling multi-path electro-magnetic signal propagation through wireless environments Rayleigh distribution is being used for more than half a century and remains as the most acceptable model till outdated. The transmission error probability calculations are less complicated in comparison to other fading model. A large number of diffracted, reflected and scattered waves from buildings, trees and rough terrain are received by mobile antenna receivers. In such environment, the channel attenuation profile measured from different field measurement closely matches with the Rayleigh distribution[13]. In FSO link both the transmitter (Tx) and receiver (Rx) is fixed and there exist a line-of-sight (LoS). The received optical pulse shape due to the effect of cloud matches closely with the Rayleigh fading model (See result section) encourage us to analysis the performance of the SISO link assuming Rayleigh fading model.

In this paper, amplitude distortions due to beam wandering for the cloud-induced fading has been considered and it has been shown how performance is degraded compared to an Additive White Gaussian Noise (AWGN) channel. Then, using average Bit Error Rate (BER) as performance metric, possible analysis is investigated by varying transmission bit rate for different optical carrier wavelengths. Then the whole performance of the system is quantified in terms of power penalty for better understanding.

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II. System Model

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 simple BLOCK diagram is shown in Fig.1.

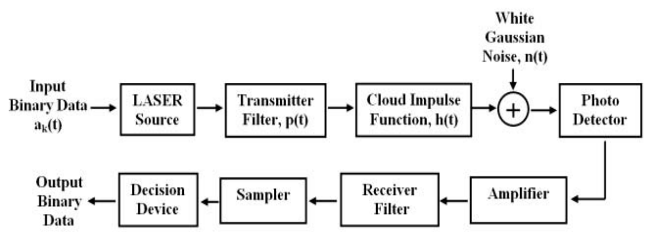

Figure 1 : Basic FSO system model

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"unpublished"[14].

III. Performance Analysis

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, and received energy. The simulation results strongly supports the use of double gamma function model to best describe optical pulse spread through clouds [15]

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

$$h(t)=\left\{k_1(c_1)t\, e^{-[k_2(c_1)]t}+k_3(c_1)t\, e^{-[k_4(c_1)]t}\right\}U(t) \qquad (1)$$

Where, h(t) is in m-2, c1 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, k1-k4 are the gammafunction constants depending on c1 and U(t) is a unit step function.

The temporal frequency transfer function can be evaluated by Fourier transforming the temporal impulse response [15]

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

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

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

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

For a given set of parameters [15]-

$$f_1=\frac{k_2}{2\pi}$$

$$f_2=\frac{k_4}{2\pi}$$

$$f_3=\frac{(k_1k_4+k_3k_2)}{2\pi(k_1+k_3)}$$

$$b=\frac{4\pi^2(k_1+k_3)}{(k_2k_4)^2}f_3^{\,2}$$

$$G=\frac{4\pi^2(k_1+k_3)}{(k_2k_4)^2}k_3^{\,2}$$

The transmitted optical signal is given by "unpublished"[14]

$$s(t)=\sqrt{2p_T}\sum_{k=-\infty}^{\infty}a_k p(t-kT_b)e^{(j\omega_c t)}$$

Where pT is the transmitted optical power, ak is the k-th information bit whose value is 1 and 0, p(t) is the optical pulse shape of bit duration Tb and carrier frequency of fc.

The received optical signal is given by

$$r(t)=\sqrt{2P_s}\sum_{k=-\infty}^{\infty}a_k g(t-kT_b)e^{(j\omega_c t)}+n_b(t)$$

Where, Ps is the received optical power and g(t)= h(t) p(t) is the received optical pulse shape which overlaps over a number of bits and produce Inter Symbol Interference (ISI) "unpublished"[14].

The photo current can be expressed as -

$$i(t)=|r(t)|^2R_d$$

$$=2R_dP_S\left|\sum_{k=-\infty}^{\infty} a_k g(t-kT_b)\right|^2 + i_n(t)$$

Where, Rd is the responsivity of the detector and in(t) is the noise current due to photo diode and receiver noise which can be expressed as

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

Without Fading

SINR can be defined as the ration of signal power to noise power [20]

$$SINR=\frac{\text{Signal Power}}{\text{Noise Power}}$$

$$=\left[\frac{I_s{}^2}{\sigma_n{}^2+\sigma_{isi}{}^2}\right]$$

Where,

$$\text{Signal Current, } i_s(t) = 2R_dP_s|a_0|^2.|g(t)|^2$$

"Mean Signal Current,"

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

Mean ISI current,

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

Where,

$$\sigma_n{}^2 = \sigma_{shot}{}^2 + \sigma_{th}{}^2$$

$$\sigma_{shot}{}^2 = 2eBI_s$$

$$\sigma_{th}{}^2 = 4KTB/R_L$$

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

$$BER=0.5\,\mathrm{erfc}\left(\frac{\sqrt{SINR}}{2\sqrt{2}}\right) \qquad (5)$$

With Fading

The analysis to a fading channel could be extended in two steps [17]-

To find the conditional probability of Bit Error $P_{b|\alpha}(\gamma_b|\alpha)$,given the amplitude fading α

To average of the conditional probability, $P_{b|\alpha}(\gamma_b|x)$ with respect to the PDF of α at α =x, in order to take into account the effect of all possible amplitude fading values on the transmission performance.

$$P_b(\bar{\gamma}_b)=\int_{-\infty}^{\infty}P_{b|\alpha}(\gamma_b|x)\,f_\alpha(x)\,dx \qquad (6)$$

Where, $\bar{\gamma}_b$ is the average received SINR/ bit with respect to α^2 and $f_\alpha(x)$ is the PDF of the amplitude fading α.

For a Rayleigh fading channel, α follows a Rayleigh distribution with PDF-

$$f_\alpha(x)=\begin{cases}\frac{x}{\sigma_\alpha^2}e^{\left(-\frac{x^2}{2\sigma_\alpha^2}\right)}, & x\geq 0\\ 0, & x<0\end{cases} \qquad (7)$$

For IM/DD it can be written-

$$P_{b|\alpha}(\gamma_b|\alpha)=\frac{\sqrt{x^2\gamma_b}}{2\sqrt{2}} \qquad (8)$$

Substituting the values from (6) and (7) in (8), hereby-

$$P_b(\bar{\gamma}_b)=\frac{1}{4}\left[1-\sqrt{\frac{\bar{\gamma}_b}{\bar{\gamma}_b+8}}\right] \qquad (9)$$

IV. Results and Discussions

Clouds having low level, noticeable vertical development and clearly defined edges are called Cumulus clouds. Cumulus clouds may appear alone, in lines, or in clusters. Cumulus clouds in appearance having the altitude of 200 and 6500 feet over the ground. This elevation range is very relevant for space communications involving planes. Cumulus clouds are often precursors of other types of clouds, such as cumulonimbus, when influenced by weather factors such as instability, moisture, and temperature gradient. Cumulus clouds are part of the larger category of cumuliform clouds, which include stratocumulus clouds, cumulonimbus clouds, cirrocumulus clouds, and altocumulus clouds[18].

A stratus cloud (St) termed as cumulus cloud because as it is formed from stratocumulus clouds, belonging to a class characterized by horizontal layering with a uniform base. 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 the study will be concentrate on cumulus clouds [19].

In this section the BER performance of SISO optical communication system in presence of cloud-induced fading modeled by Ray-Leigh function has been compared. For doing this, the numerical results of BER of the FSO link have been presented. The system has been simulated for the given set of Gama function constant for different wavelengths listed below.

Table 1 : Double gamma function constants: Cloud thickness=200 m [15]

Gamma Function Constant	Wavelengths		
	0.532 µm	0.8 µm	1.3µm
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

Table 2 : Double gamma function constants: Cloud thickness=250 m [15]

Gamma Function Constant	Wavelengths		
	0.532 µm	0.8 µm	1.3µm
k_1	12.4	5.2	2
k_2	1.1×10^7	0.83×10^7	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

Fig. 2, demonstrate the received optical pulse shape. In this case the transmission bandwidth is considered 1GHz. It shows that the amplitude of the received bit is fluctuating for the total bit interval.

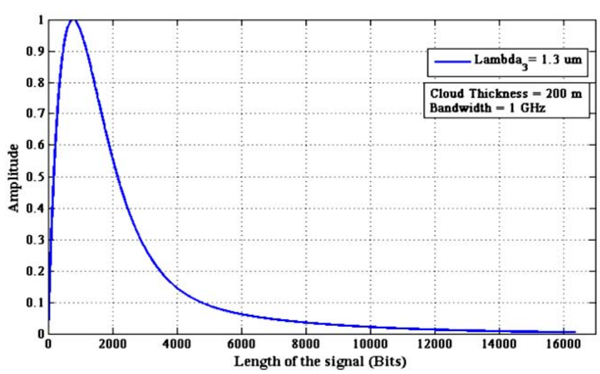

Figure 2 : Received optical pulse shape

Fig. 3, demonstrate the optical pulse shape for different amplitude fading considering the Rayleigh fading which is quite similar to the received optical pulse shape in fig. 1.

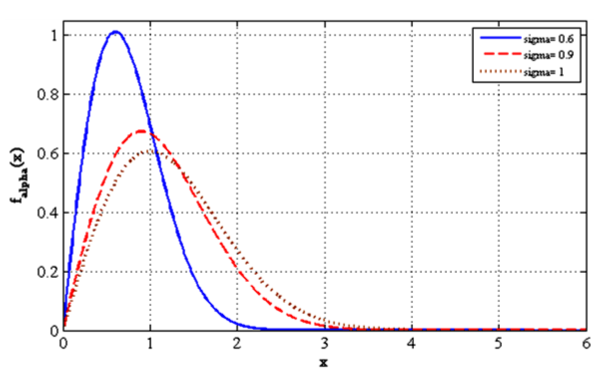

Figure 3 : Received optical pulse shape considering Rayleigh fading model

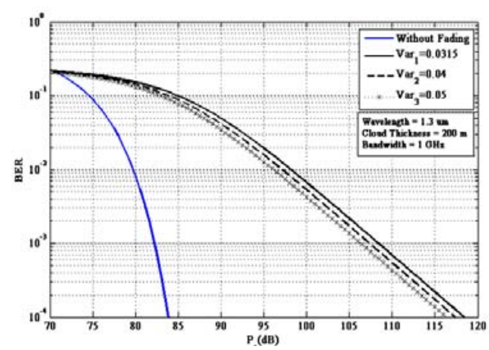

Figure 4 : BER performance of a FSO link with fading for different variance

It has been assumed that the Inter Symbol Interference (ISI) is available and Fig. 4, present the graphical representation of BER vs. received power in decibel considering the effect without fading and for different value of amplitude fading **α**. It demonstrate that for achieving a BER of 10-4considering the effect of fading it is needed to change the power level significantly in numerical value more than 1 kilo-Watt (KW).

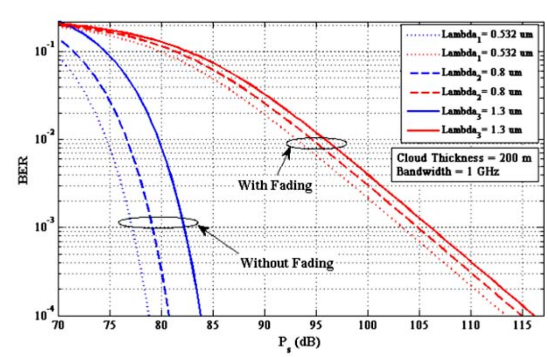

Figure 5 : BER performance of a FSO link with fading effect for Intensity Modulation Direct Detection (IM/DD)

In Fig. 5, the effect of fading for all carrier wavelengths considering the transmission bandwidth of 1GHz has been demonstrated. It shows that there are no significant advantages for any particular transmission wavelength.

For further investigation we varied the transmission bandwidth for different carrier wavelength communication. Fig. 6, 7 and 8 illustrate the BER performance of a SISO link for various bandwidths.

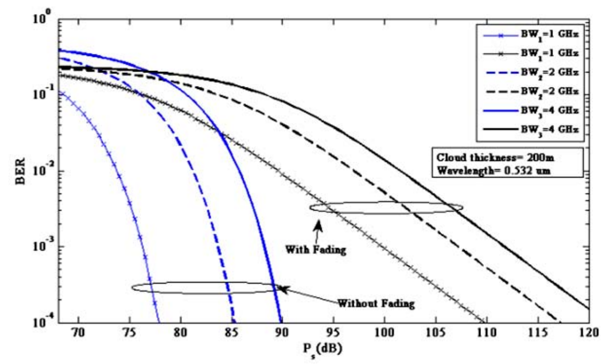

Figure 6 : BER performance of a FSO link with fading effect for different bandwidths

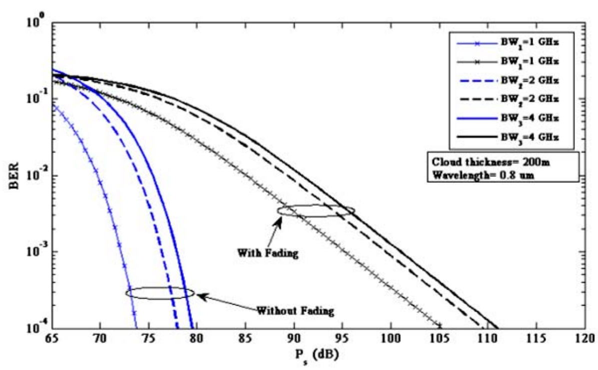

Figure 7 : BER performance of a FSO link with fading effect for different bandwidths.

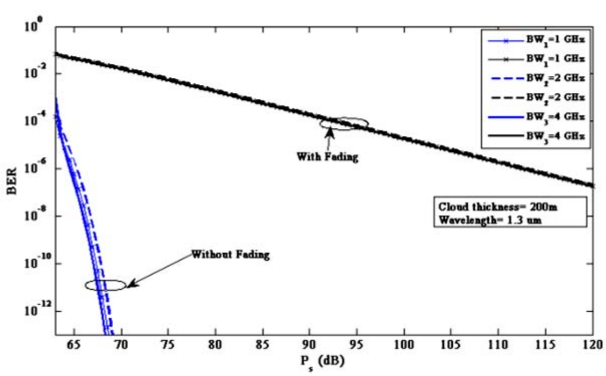

Figure 8 : BER performance of a FSO link with fading effect for different bandwidths

Fig. 8 depicts that, when the transmission bandwidth increases the received power needs to be increased. But for the wavelength of 1.3µm all the performance curves close to each other for various bandwidths.

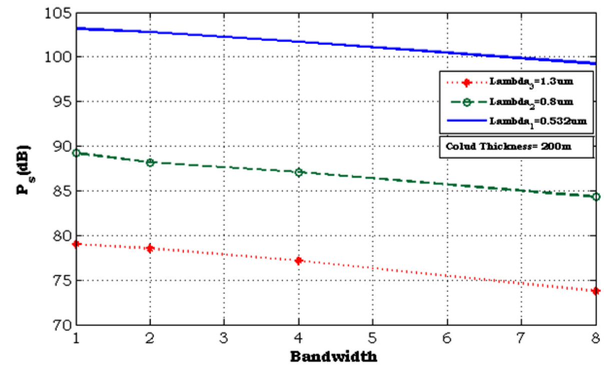

Figure 9 : Power penalty for different bandwidths (Cloud Thickness=200m)

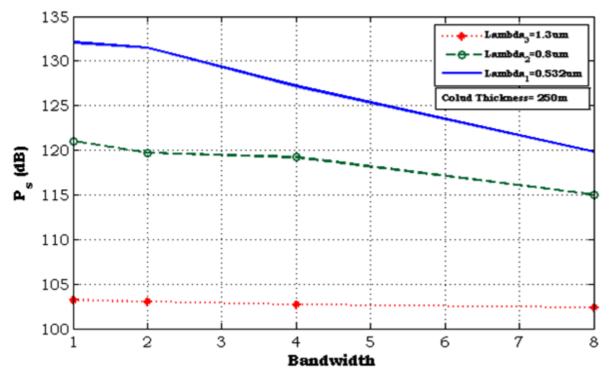

Figure 10 : Power penalty for different bandwidths (Cloud Thickness=250m)

Fig.9 and Fig. 10 depict the required optical power in dB for various transmission bandwidths for maintaining a bit error rate (BER) of 10-5.

From Fig.9, the required optical power (for the cloud thickness of 200 m) to overcome the inter symbol interference varies about 74 dB to 79 dB for a wide range of transmission bit rate (1Gb/s - 8 Gb/s) for the carrier wavelength of $\lambda=1.3$ μm. While the required optical power for the wavelength of $\lambda=0.8$ μm is about 84 dB to 89 dB; as for $\lambda=0.532$ μm the value is about 99 dB to 103 dB for the same bit rate. This analysis will surely help to choose the type of photo detector for the FSO link depending on the optical power budget.

In Fig.10, the required optical power (for the cloud thickness of 250 m) to overcome the inter symbol interference varies about 102 dB to 103 dB for a wide range of transmission bit rate (1Gb/s - 8 Gb/s) for the carrier wavelength of $\lambda=1.3$ μm while maintaining the mentioned BER. The required optical power for the wavelength of $\lambda=.8$ μm is about 115 dB to 121 dB. Whereas for $\lambda=.532$ μm the value is about 119 dB to 132 dB for the same bit rate.

So it can be said the power penalty is also in considerable level for the wavelength of 1.3µm.

V. Conclusion

In this paper, a very basic approach to performance analysis of SISO free space optical systems (FSO) due to the cloud-induced fading has been presented which was modelled as Ray Leigh fading. The proposed technique is based on finding the conditional probability of Bit Error, for given amplitude fading α and then averaging the conditional probability, with respect to the PDF of α, which is considered to follow the Ray Leigh distribution. It has been investigated that the BER performances for various optical wavelength communications by varying bandwidth. It is found that for the communication wavelength of 1.3μm, the received power is same for different transmission bandwidth. For high bandwidth transmission, wavelength of 1.3μm is preferable and power penalty is also considerable for that wavelength. But for all the cases required power budget is high.

References Références Referencias

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, July 2006, Vol. 18, No. 14.
2. S. Mohammad Navidpour and Mohsen Kaverhrad, "BER Performance of Free Space optical Transmission with Spatial Diversity", IEEE Transactions on Wireless Communications, August 2007, Vol. 6, No. 08.
3. B. R. Strickland, M. J. Lavan, E. Woodbridge, and V. Chan, "Effects of fog on the bit-error rate of a free space laser communication system", Applied Optics, Jan. 1999, vol. 38, no. 3, pp. 424-431.
4. S. Arnon, "Effects of atmospheric turbulence and building sway on optical wireless communication systems", Optics Letter, Jan. 2003, vol. 28, no. 2, pp. 129-131.
5. Zhu X, Kahn J M, "Performance bounds for coded free-space optical communications through atmospheric turbulence channels, IEEE Trans. Commun, 2003, 51(8):1233-1239.
6. Uysal M, Navidpour S M and Li J, "Error rate performance of coded free-space optical links over strong turbulence channels", IEEE Communication, 2004, Lett. 8(10): 635-637.
7. 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 Communication, 2006, 5(6): 1229-1233.
8. Ehsan Bayaki, Robert Schober, and RanjanK.Mallick, "Performance Analysis of Free–Space Optical Systems in Gamma–Gamma Fading", IEEE Global Communications Conference (Globe COM), New Orleans, Dec. 2008.
9. Farid A A, HranilovicS, "Outage capacity optimization for free-space optical links with pointing errors", IEEE/OSA J. Lightwave Technology, 2007, 25(7): 1702-1710.
10. Sandalidis H G, Tsiftsis T A, Karagiannidis G K, UysalM, "BER performance of FSO links over strong atmospheric turbulence channels with pointing errors", IEEE Commun., 2008, Lett. 12(1): 44-46.
11. T. A. Tsiftsis, H. G. Sandalidis, G. K. Karagiannidis and M. Uysal, "FSO links with spatial diversity over strong atmospheric turbulence channels," in Proc. IEEE Intern. Conf. Commun. (ICC), May 2008, pp. 5379–5384.
12. Alexander Vavoulas, Harilaos G. Sandalidis, and Dimitris Varoutas, "Weather Effects on FSO Network Connectivity"J. OPT. COMMUN. NETW./VOL. 4, NO. 10/OCTOBER 2012.
13. Chandra A. , Bose C. and Bose M. "Unified BER and optimum threshold analysis of binary modulations in simple and cascaded Rayleigh fading channels with switched combining" Int. J. Commun. Syst. 2011; 24:153–167.
14. Hasan M., Majumder S. P., Das P., "Effects of cloud on the bit error rate(BER) performance of a FSO link", unpublished.(On review), Journal of Laser and Optics Technology, Elsevier,USA,2013
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, 1994, Vol. 41, No. 8, 1591-1605
16. John. M. Senior, Optical Fibre Communications-Principles and Practice, 3rd edition., Pearson Education, 2003.
17. Jon W. Mark and Weihua Zhuang, Wireless Communications and Networking, Pearson Education, 2003.
18. "Details about Cumulus Cloud - Cumulus_cloud ," [online]. Accessed on December 2012. Available: http://en.wikipedia.org/ wiki/Cumulus_cloud
19. "Common information about Stratus CLoud-Stratus Cloud," [online]. Accessed on December 2012. Available: http://en.wikip edia.org/wiki /Stratus _ cloud.
20. Pranjan Das, "Analysis of a Free Space Optical (FSO) Link Under The Influence of Spatial Widening Effect From Propagation Through Clouds", 2011.