Performance Evaluation of Free Space Optics (FSO) and Radio Frequency Communication System Due to Combined Effect of Fog and Snow

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ABSTRACT

Free space optics provides high data rate by allowing transmission of signal through atmosphere. The free space optics is also effected by different weather conditions. The atmospheric attenuation is caused by two main factors i.e. Absorption and Scattering. Fog, rain, snow and cloud causes the scattering of optical signals transmitted in free space. Fog is the most critical attenuating factor. The Snow Attenuation is also more severe than the Rain Attenuation due to large droplet size of snow. The hybrid FSO/RF system is considered for providing high availability. Frequencies in GHz range can improve the availability and it is selected as a back-up link. In this paper the effect of fog and snow on the performance of FSO and RF system is evaluated.

General Terms

Weather Conditions, Fiber optics and Matlab.

Keywords

Introduction, Fog, Snow and Performance evaluation of FSO and Radio frequency System (RF) due to Fog and Snow effect.

1. INTRODUCTION

A FSO uses a laser beam to transmit data through atmosphere from transmitter to receiver. In the 700–10,000-nm wavelength range there are several atmospheric transmission windows. But the majority of free-space lasercom systems are designed to operate in the windows of 780–850 and 1520–1600 nm.

Fog affects the FSO signal for different wavelength and visibility conditions related to heavy fog and thin fog. The different models are considered for determining the Attenuation in case of fog. The dry and wet snow rate is considered in case of snow attenuation.

This paper has been organized as follows: After introduction in section 1, the performance evaluation of FSO and RF system for different climatic conditions i.e. fog and snow is described in Section 2. The simulations are performed in Section 3 to show the combined effect of fog and Snow on FSO and RF system and Conclusions are drawn in Section 4.

2. PERFORMANCE EVALUATION OF FSO AND RF SYSTEM

The performance of a lasercom system is generally quantified by the Power received, "link margin", i.e., the ratio, expressed in dB, of the signal power received to the signal power required to achieve a specified data rate. The link margin calculation is therefore essential to design a acceptable system [10].

1.1 Received Power for FSO

Consider a laser transmitting a total power $P_{transmitter}$at the wavelength 850 nm. The signal power received at the communications detector can be expressed as [1]

$$P_{Receiver}=P_{Transmitter}D^{T}2/((\lrcorner div^{T}2\ L)\ 10^{-\gamma L/10}\tau_{tranmitter}\tau_{receiver} \qquad (1)$$

For fog and Snow

$$P_{Receiver}=P_{Transmitter}D^{T}2/((\lrcorner div^{T}2\ L)\ 10^{-(\gamma_{fog+snow})L/10}\tau_{tranmitter}\tau_{receiver} \qquad (2)$$

where *D* is the receiver diameter, θ_{div} is the full transmitting divergence angle, γ is the atmospheric attenuation factor (dB/km) due to fog and snow, $\tau_{transmitter}$ and $\tau_{receiver}$ are the transmitter and receiver optical efficiency respectively [1].
The parameters used in FSO calculations are shown in table 1.

1.1.1 Specific Attenuation due to Fog

Fog can be described as a cloud of small particles of water, smoke, ice or combination of these near the earth surface thereby scattering the incident light and hence reducing the visibility. The specific attenuation for both Kim and Kruse model is given by [2]

$$\beta(\lambda)=\frac{\mathbf{10logV\%}}{\mathbf{V}}(\lambda/\lambda_o)^{-q} \qquad (3)$$

Here *V(km)* stands for visibility, *V%* stands for transmission of air drops to percentage of clear sky [3,4], λ in nm stands for wavelength and $\lambda_0$as visibility reference (550 nm). For Kruse model [2]

$$q=\begin{cases} 1.6 & \text{if } V > 50km \\ 1.3 & \text{if } 6km < V > 50km \\ 0.585V^{\frac{1}{3}} & \text{if } V < 6km \end{cases} \qquad (4)$$

The attenuation of 1550 nm is expected to be less than attenuation of shorter wavelengths. Kim rejected such wavelength dependent attenuation for low visibility in dense fog. The *q* variable in equation (3) for Kim model [2] is given by

$$q=\begin{cases} 1.6 & if V > 50km \\ 1.3 & if\ 6km < V > 50km \\ 0.16V + 0.34 & if\ 6km < V < 1km \\ V - 0.5 & if\ 0.5km < V < 1km \\ 0 & if V < 0.5km \end{cases} \quad (5)$$

Al Naboulsi et al. has provided relations to predict fog attenuation. It characterizes advection and radiation fog separately. The advection fog is formed by the movements of wet and warm air masses above the colder maritime and terrestrial surfaces. Al Naboulsi [2] provides the advection fog attenuation coefficients as

$$\gamma_{ADV}=\frac{0.11478\,(\,+\,3.8367}{V} \quad (6)$$

Radiation fog is related to the ground cooling by radiation. Al Naboulsi provides the radiation fog attenuation coefficients as

$$\gamma_{RAD}=(0.18126(^{\dagger}2+0.13709''\,(''\ +3.7502)/V \quad (7)$$

The specific attenuation for both types of fog is given by Al Naboulsi as follows

$$\alpha_{Spec}(dB/km)=\frac{10}{\ln(10)}\gamma(\lambda) \quad (8)$$

Table 1

Parameters used in FSO calculation [1]

Parameter	**Values**
Transmitter optical power(mw)	5
Divergence angle (mrad)	1.5
Receiver diameter(cm)	15
Laser Wavelength (nm)	850
Transmitter efficiency	0.5
Receiver efficiency	0.5
Receiver Sensitivity (dBm)	-20

1.1.2 Specific Attenuation due to Snow

Similarly the FSO attenuation due to snow has been classified i into dry and wet snow attenuations. If S is the snow rate in mm/hr then specific attenuation in dB/km is given by [5,6]

$\alpha_{snow}=aS^b$ dB/km (9)

If λ is the wavelength, *a* and *b* are as follows for dry snow[5,6]

$a=5.42*10^{-5}\lambda+5.4958776$

$b=1.38$

The same parameters for wet snow are given as follows [5,6]

$a=1.023*10^4\lambda+3.7855466$

$b=0.72$

1.1.3 Snow Attenuation for visibility

The attenuation in case of snow can be more severe than the attenuation in case of rain due to the much larger droplet size. Based on empirical model, the attenuation for snow based on visibility range is [8]

$\alpha=58/V$ (10)

Where α is the Specific attenuation in dB/km and V is the visibility in km.

So the value of specific attenuation due to fog and snow are calculated from eq. (3), (9) and (10). The values calculated are shown in table 1(a) and 1(b).

Table 2(a)
Typical values of attenuation of fog for kim model with corresponding visibilities

For Kim model

Wavelength (nm)	Climate	Visibility (km)	Attenuation (dB/km)
850	Heavy fog	0.5	26
	Thin fog	1.5	6.379
	Clear	20	0.1690

Table 2(b)
Typical values of attenuation of snow for snow rate with corresponding visibilities

Wavelength (nm)	Snow Rate	Visibility (km)	Attenuation (dB/km)
850	8mm/hr	0.5	116
	4mm/hr	1.5	38.667

2.2 Link margin for FSO

Link margin is defined as the ratio of available received power to the receiver power required to achieve a specified BER at a given data rate. The required power at the receiver $P_{requried}$is related by $P_{requried}=N_bRhc/\lambda$. Combining the above equations yields the link margin expression [1]

$$LM=[P_{Transmitter}(\lambda/N_bRhc)]_{*}D^{\intercal}2/((_{\downarrow}div^{\intercal}2\ \ L)\ 10^{(\gamma_{fog+snow})L/10}\tau_t\tau_r \quad (11)$$

Where *D* is the receiver diameter, θ_{div} is the full transmitting divergence angle, γ is the atmospheric attenuation factor (dB/km) due to fog and snow, τ_t and τ_r are the transmitter and receiver optical efficiency respectively [1].Ep=hc/λ is the photon energy at wavelength λ and N_b is the receiver sensitivity (photons/bit).

Similarly for Link Margin the attenuation factor for fog and snow is calculated. The link margin value shows how much margin a system has at a given range to compensate for scattering, absorption and scintillation losses.

2.3 Data Rate for FSO

Given the receiver sensitivity −20 dBm, which is equivalent to 327000 photons/bit at wavelength 850 nm, the achievable data rate *R* can be obtained from [1]

$$R=P_{Transmitter}D^2 10^{-(\gamma_{fog+snow})L/10}\tau_t\tau_r/\pi(\theta_{div}/2)^2L^2N_bE_P \quad (12)$$

Where *D* is the receiver diameter, θ_{div} is the full transmitting divergence angle, γ is the atmospheric attenuation factor (dB/km) due to fog and snow, τ_t and τ_r are the transmitter and receiver optical efficiency respectively. Ep=hc/λ is the photon energy at wavelength λ and N_b is the receiver sensitivity (photons/bit).

2.4 Bit error rate (BER) for FSO

For the performance of FSO system the SNR and BER is considered. As the Fog effect more than other weather conditions. So the effect of Fog and Snow is considered. [11]

The shot noise, surface leakage current noise and dark noise is given by

$$\sigma^2_{sig\text{-}shot}=2q(R_oP_R)M^{x+2}B \quad (13)$$

$$\sigma^2_{surf}=2qI_LB \quad (14)$$

$$\sigma^2_{dark}=2qI_DM^{x+2}B \quad (15)$$

The Johnson noise is given by [12]

$\sigma^2_{johnson}=4kTB/R_L$ (16)

$SNR=(R_oMP)^2/(2qR_oP_R+I_D)M^{x+2}B+2qI_LB+4kTB/R_L)$ (17)

where I_D is the bulk dark current, I_L is the surface leakage current, $F(M) \cong M^{x}$ $(0 < x < 1)$ is the excess noise factor, k is the Boltzmann constant, *B* is the equivalent noise bandwidth and T is the system temperature.

The Bit error rate(BER) can be written as [13]

$$BER=\frac{1}{2}erfc\left(\frac{1}{2\sqrt{2}}\sqrt{\frac{S}{N}}\right) \qquad (18)$$

Table 3
Parameters for optical communication link with APD detector [11]

Parameter	Values
Transmitter Antenna diameter D_t	10cm
Wavelength(nm) λ	850nm, 1550nm
Excess noise factor x	0.5
Surface dark current I_D	0.5nA
Surface leakage current I_L	0nA
Equivalent resistance R_{eq}	50kΩ
Electrical Bandwidth B	25MHz
Noise Temperature T	290k

2.5 Received Power for RF system

For directional RF transmission through free space, there is always significant attenuation from beam divergence. Assuming uniform transmit and receive antennas with antenna gain G, the received power can be written as [11]

$P_R=G^2(\,(/4(L\ )^2P_T\,\tau_{RF}\tau_t\tau_r$ (19)

$G_{T/R}=(\pi D_{T/R}/\lambda)^2$ (20)

Where G is the Transmitter and Receiver Gain. P_T is the transmitted power. τ_t and τ_r are the RF antenna efficiencies for the transmitter and receiver. τ_{RF} mainly involves Fog and Snow attenuation in RF systems. It is written in terms of atmospheric attenuation α in dB/km given by $-10\log(\tau_{RF})/L$.

2.5.1 *Specific attenuation for RF system due to fog effect*

Total water content per unit volume can be used to express attenuation. The specific attenuation is given as [2,5]

$\gamma_c=k_lM$ (21)

where γc: Specific attenuation in dB/km
K_l: Specific attenuation coefficient ((dB/km) /(g/m^3))
M : liquid water density in cloud or fog (g/m^3)

2.5.2 *Specific attenuation for RF system due to Snow effect*

This indicates that the snow attenuation may be increasingly important as wavelengths get short The specific snow attenuation A in terms of snow rate R for GHz links is given as follows

$A=0.0349^{R^{T}1.6/(^{T}4}\ +0.00224^{R/(}$ (22)

The parameters are obtained from table 4.

Table 4
Typical parameters for RF communication system [11]

Parameter	**Values**
Transmitter antenna efficiency, τ_t	0.5
Receiver antenna efficiency, τ_r	0.7
Transmitter antenna diameter, D_t	0.18 m
Receiver antenna diameter, D_r	64 m
Wavelength, λ	3.54 cm, 3mm
Transmitter power, P_t	5mW
Equivalent registance, R_{eq}	50 kΩ
System temperature, T	290 K

For the higher frequency the transmitter diameter is 0.018m. For fog and snow the attenuation is calculated from equation (21) and (22) as shown in Table 5.

Table 5
Attenuation values for different atmospheric conditions

Climate		**Frequency**	**Attenuation in dB/Km**
Fog		50 GHz	0.3465
		100 GHz	0.6509
Snow	Snow Rate 10mm/hr	50 GHz	0.6320
		100 GHz	1.1094

2.6 Bit error Rate (BER) for RF system

For the RF link, the Johnson noise for a system at temperature *T* is given by [12]

$\sigma^2_{johnson}=4kTB/R_{eq}$ (23)

and the SNR is [12]

$SNR=(P_R/R_{eq})/(4kTB/R_{eq})$ (24)

where R_{eq} is the equivalent resistance, k is the Boltzmann constant, *B* is the equivalent noise bandwidth and T is the system temperature.

and the BER is given by [13]

$$BER=\frac{1}{2}erfc\left(\frac{1}{2\sqrt{2}}\sqrt{\frac{S}{N}}\right) \qquad (25)$$

Typical parameters for deep space communication links operating in the X-band are shown in Table 4. [11]

3. RESULTS AND DISCUSSION

Simulation is carried out to show the combined effect of Fog and Snow effect on hybrid FSO/RF system.

The performance of FSO system and RF system can be evaluated by the received optical power, link margin, Data rate and BER of the system. So the received power due to the effect of fog and Snow can be evaluated.

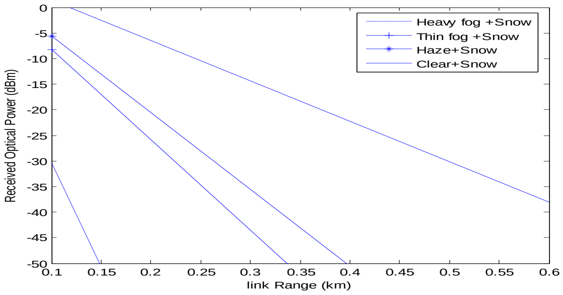

Fig 1: Received optical power versus link range for different Fog Conditions and Snow

The received power depends upon the different parameters. The power received is achieved for heavy fog and snow at a distance less than 0.15 km, for thin fog and Snow at distance less than 0.35 km, for Haze and Snow at a distance less than 0.4 km and for Clear and Snow at distance less than 0.5 km.

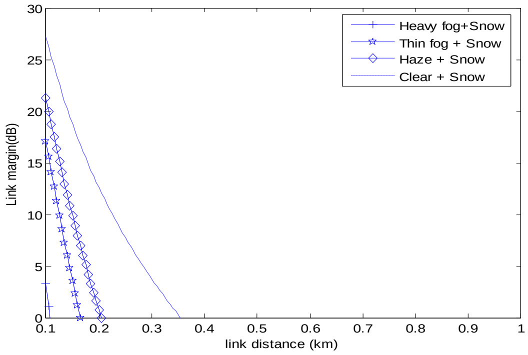

Fig 2: Link margin versus link range for different Fog and Snow

The link margin depends upon the different parameters. The link margin for receiver responsivity-25 dBm is achieved for heavy fog and snow at a distance less than 0.1 km, for thin fog and Snow at distance less than 0.25 km, for Haze and Snow at distance less than 0.3 km and for Clear and Snow at distance less than 0.55km as shown in fig 2.

The data rate of 1Gb/s is obtained for heavy fog and Snow at a distance of 0.9 km, for Thin fog at distance of 0.2 km, for Haze and Snow at distance less than 0.3 km and for Clear and Snow at distance less than 0.5km as shown in fig. 3.

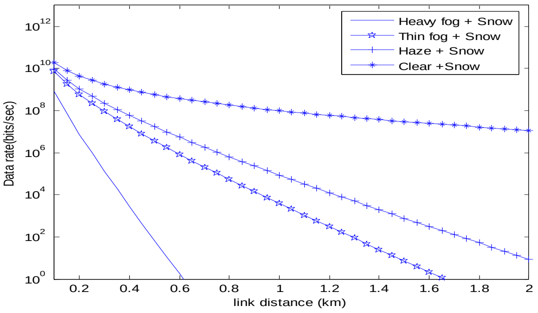

Fig 3: Data rate versus link range for different Fog and snow

Thus different data rates are obtained for different visibility conditions.

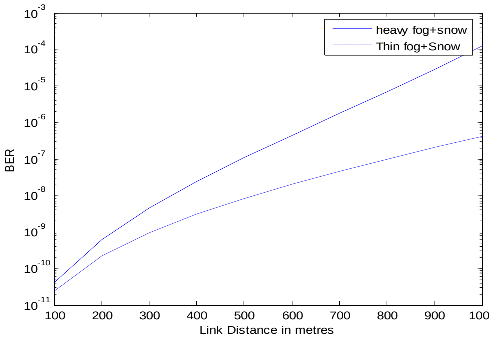

Fig 4: BER v/s Link Distance for Fog and Snow

In fig 4 the combined effect of fog and snow on BER is calculated. For the heavy fog (v=0.5km) and Snow the BER value is high than the thin fog (v=1.5km) and Snow. So as the visibility decreases the BER increases as the link distance increases.

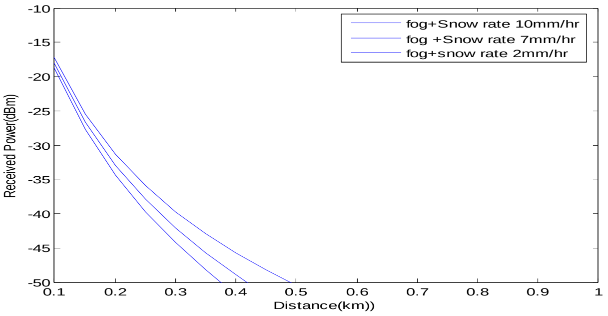

Fig 5: Received Power v/s Distance for Fog RF and Snow RF

The received power for RF system due to effect of fog and snow is shown in fig 5. The received power for fog and different Snow rate is obtained at a distance less than 0.4km, 0.45km and 0.5km.

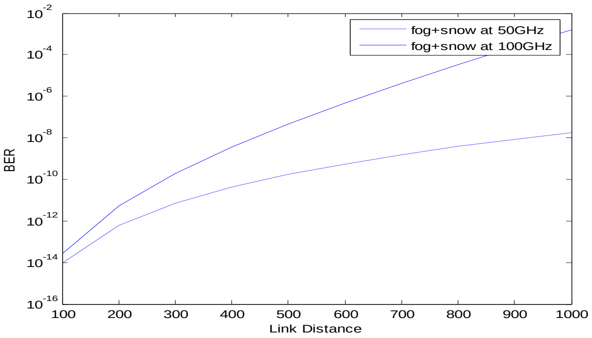

Fig 6: BER v/s Link Distance for Fog and Snow RF

The BER for RF system effected by fog and snow is less than FSO system. As the frequency increases the BER increases as shown in fig 6. The BER for combined effect of Fog and Snow on FSO system is greater than the RF system. So in case of blockage of FSO link the RF link is used as back-up.

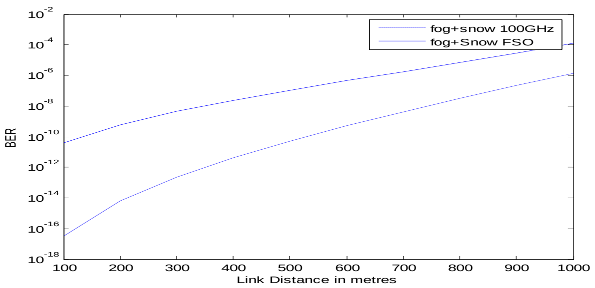

Fig 7 Comparison of BER v/s Link Distance for Fog and Snow FSO and RF

The Specific attenuation due to combined effect of Fog and Snow increases. So the BER for the FSO and RF system is determined from fig 4 and fig 6.

The BER for heavy fog (v=0.5km) and for Snow rate 2mm/hr is obtained.

4. CONCLUSION

FSO systems offer a viable solution toward building optical connectivity in a cost effective, quick, and reliable manner in certain situations. But the weather conditions i.e. Fog and Snow effects the free space optics. The received power, link margin and data rate are evaluated for FSO system. The BER for FSO system due to combined effect of fog and snow is more than the BER of RF system. So RF is used as back-up link. So that signal can be switched to RF when FSO is blocked due to atmospheric effects.

5. REFERENCES

[1] HU Guo-yong, CHEN Chang-ying, CHEN Zhen-qiang. 2006. Free-Space Optical communication using visible light ,SPIE 2006

[2] F. Nadeem, B. Flecker, E. Leitgeb , M. S. Khan, M. S. Awan , T. Javornik. 2008. Comparing The Fog Effects on Hybrid Network Using Optical Wireless and GHz Links, 2008

[3] Isaac I. Kim, Bruce McArthur, and Eric Korevaar Optical Access Incorporated 10343 Roselle Street San Diego, CA 92121, “Comparison of laser beam propagation at 785 nm and 1550 nm in fog and haze for optical wireless communications”.

[4] A.P. Lenham and M. R. Clay, 1982. Drop-size distribution of fog droplets determined from transmission measurements in the 0.53-10.1 µwavelength range, Appled Optics Vol. 21, No. 23, pp 4191 [1982].

[5] F. Nadeem, E. Leitgeb , M. S. Awan, 2009. Comparing The Snow Effects on Hybrid Network Using Optical Wireless and GHz Links, IEEE 2009.

[6] S.S. Muhammad, P. Kuhldorfer and E. Leitgeb, 2005. Channel Modeling for Terrestrial Free Space Optical Links, ICTON, IEEE, p.407 (2005).

[7] M. S. Awan, Marzuki, E. Leitgeb, F. Nadeem, M. S. Khan, C. Capsoni, 2003. Weather Effects Impact on the Optical Pulse Propagation in Free Space, ConTEL 2003.

[8] F. Nadeem, V. Kvicera, M. S. Awan, E. Leitgeb, S. S. Muhammad, G. Kandus, 2009. Weather Effects on Hybrid FSO/RF Communication Link, IEEE J. Sel. Areas in Comm., vol.27, no.9, Dec. 2009.

[9] M. Gebhart, E. Leitgeb, J. Bregenzer, 2003. Atmospheric effects on Optical Wireless links, ConTEL 2003.

[10] Majumdar, J. Ricklin, (eds.), 2005. Free Space Laser Communications, Springer Textbooks, 2005.

[11] MorioToyoshimaa,b, Walter R. Leeba, HirooKunimorib,c, and Tadashi Takanod, 2005. Comparison of microwave and light wave communication systems in space applications, 2005.

[12] A. Akbulut, H. Gokhan Ilk, F. Arı, 2005. Design, Availability and Reliability Analysis on an Experimental Outdoor FSO/RF Communication System, Tu.B3.4 ICTON 2005, pp 403-406.

[13] HebaYuksel, 2005. Studies of the Effects of Atmospheric Turbulence on Free Space Optical Communications., Ph.D. Dissertation, Univ. of Maryland,College Park, 200