Effect of Atmospheric Attenuation on Laser Communications for Visible and Infrared Wavelengths

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Abstract

A theoretical study and analysis of the effect of some weather parameters on the laser light source of optical signal in free space (FSO), were discussed. The effect of these parameters on attenuation coefficient of the laser beam was calculation at wavelengths (650, 785 and 1550) nm. The attenuation coefficient was (0.698, 0.546 and 0.225) dB/km for wavelengths (650, 785 and 1550) nm respectively at a visibility of 20 km. We studied as well the receiver optical power, data transfer rate and link margin under the influence of the weather conditions. It was found that weather conditions such as (clear, haze, thin fog, light fog, heavy fog) effect on those wavelength at different ways. It is feasible to enhance the system performance such as link range and data transfer rate by increasing transmitting power and decreasing laser beam divergence angle.

Keywords: Laser Communications, Visible wavelength, Infrared wavelength, Free Space.

Introduction

Effect of atmospheric attenuation such as rain, haze and fog on laser communications (data transfer rate) were studied in [1-4]. Wireless laser communication, called free space optical communication as well, is a kind of new communication technologies with free space or air as its transferring medium in which the carrier wave transfers the effective information to realize the communication. Wireless laser communication has the convenience of the radio communication as well as the major advantages of fiber communication, especially has the character of big communicating vacuum comparing with the traditional communicating ways, it has many advantages such as high transferring speed, fine line beam direction, high privacy, without the allowance of radio frequency usage, not influencing the municipal construction, low cost, wide communication frequency band. Especially because laser has the high direction, thin emitting light beam, and enables to transfer quite a lot of data in the short time, it has the short communication time, high privacy and interference immunity and can prevent from being wiretapped and detected effectively etc, laser has a wide application in civil and military fields, and becomes a new communication technology with the high competitive ability, [5].

Atmospheric effects are different according to the systems used: radio-relay systems, microwaves, laser beams, etc., [6]. The optimization of these effects goes through the choice of an adequate wavelength presenting a minimum of attenuation for the transmitted signal under various atmospheric conditions. Among these, fog is a very important factor in electromagnetic radiation degradation and especially for visible and IR waves. We have known that penetration of light through a dense fog is much more difficult than through a heavy shower. In fact, in this case the size of the particles (fine water droplets of a diameter lower than 100 μm) is of the same order as the used wavelength, [7, 8].

Light Propagation in the Atmosphere

In visible and IR wavelengths, light propagation through the atmosphere is affected by two phenomena: absorption and scattering by air molecules and absorption and scattering by solid or liquid suspended particles present in the atmosphere. These are aerosols such as dust, haze, mist, and fog [9, 10]. According to Beer-Lambert's law, the received irradiance at a distance L from the transmitter is related to the transmitted irradiance by the following model [11]:

$$\tau(\lambda, L) = \frac{P_R}{P_T} = \exp(-\gamma(\lambda), L) \quad \text{......................(1)}$$

where:

$\gamma(\lambda)$: represent the total attenuation coefficient m^{-1}

P_R: the received optical power at a distance L,

P_T: the transmitted optical power at the optical source

$\tau(\lambda, L)$: the transmittance of the atmosphere at wavelength λ.

The total attenuation coefficient varies depending on the presence of precipitation and this attenuation coefficient is the sum of the absorption and the scattering coefficients from aerosols and molecular constituents of the atmosphere, so:

$$\gamma(\lambda) = \alpha_m(\lambda) + \alpha_a(\lambda) + \beta_m(\lambda) + \beta_a(\lambda) \quad \text{........(2)}$$

The first two terms on the right hand side represent the molecular and aerosol absorption coefficients, and the last two terms are the molecular and aerosol scattering coefficients respectively. Ignoring the attenuation contribution by molecular & aerosol absorption and molecular scattering as it is very small when compared with attenuations due to aerosol scattering, the equation (2) is thus reduced to:

$$\gamma(\lambda) = \beta_a(\lambda) \quad \text{...(3)}$$

In order to compute attenuations caused by fog and snow effects, mostly we rely on empirical approaches as they are convenient when compared to very complex and time consuming theoretical approaches based on microphysical models. The most common empirical model is based on visibility range estimate. Based on the visibility range estimate with a 2% transmission threshold over the atmospheric path, fog attenuation can be estimated by [12]:

$$\gamma(\lambda) \cong \beta_a(\lambda) \cong \frac{17.35}{V}\left(\frac{\lambda}{550}\right)^{-q} \quad \text{......................(4)}$$

where V is visibility range in km, λ is transmission wavelength in nm. $\gamma(\lambda)$ is the total extinction coefficient for fog and q is the size distribution coefficient of scattering related to size distribution of the fog droplets. The parameter q in eq.(4) depends on the visibility distance range and is given by the following equation [12]:

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

Link Analysis

The purpose of this section is to develop the parameters necessary to calculate the performance of an optical communication link. We shall consider the situation of optical propagation between points in free-space. Consider a laser transmitting a total power P_T at the wavelength (650, 785, 1550) nm. The signal power received at the communications detector can be expressed as [13]

$$P_R = P_T \frac{D^2}{\theta^2 L^2} 10^{-\gamma L/10} \tau_T \tau_R \quad \text{.........................(6)}$$

where D is the receiver diameter, θ is the divergence angle, γ is the atmospheric attenuation factor (dB/km), τ_T, τ_R are the transmitter and receiver optical efficiency respectively.

Link Margin and Data Rate

Another important parameter in optical communications link analysis is "Link Margin", which is the ratio of available received power to the receiver power required to achieve a specified BER at a given data rate. Note that the "required" power at the receiver P_{REQ} (watts) to achieve a given data rate, R (bits/sec), we can define the link margin LM as [13]:

$$LM = [P_T \lambda / N_b R h c] \times [D^2 / \theta^2 L^2] 10^{-\gamma L/10} \tau_T \tau_R \quad \text{....................................(7)}$$

where R is a data rate, h is a plank constant and c is the light velocity.

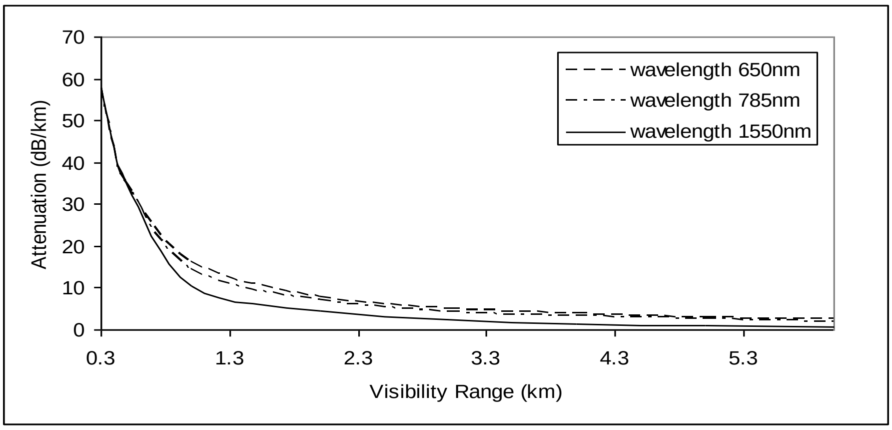
Given a laser transmitter power $P_{transmitter}$, with transmitter divergence of θ, receiver diameter D, transmit and receive optical efficiency $\tau_{transmitter}$, $\tau_{receiver}$ the achievable data rate R can be obtained from [14]:

$$R = \frac{P_T P_R 10^{-\gamma L/10} D^2}{\pi(\theta/2)^2 L^2 E_p N_b} \quad \text{.................................(8)}$$

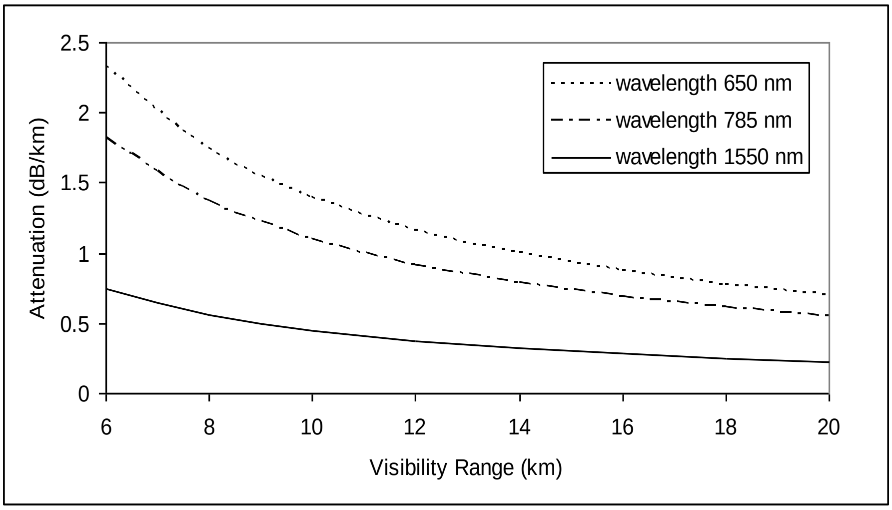
where E_p = hc/λ, is the photon energy at wavelength λ and N_b is the receiver sensitivity (photon/bits) or (dBm).

Results and Discussion

We shall consider in detail the situation of optical propagation between two points in terrestrial applications. Therefore attenuation coefficient, received optical power, data rate and link margin of 650 nm, 785 nm and 1550nm laser beam was studying in this work. Hence, Fig. (1) compares the attenuation coefficient of 650 nm, 785 nm and 1550 nm wavelengths depend on eq.(4). It was found that the wavelength from visible light all way up to infrared wave has almost no effect on propagation range under short range-conditions.



(a)



(b)

Fig.(1) Comparison of attenuation among laser beam of different wavelengths. (a) Low visibility; (b) High visibility.

Some typical values of terrestrial short-range path attenuations for 650nm, 785 nm, 1550 nm laser waves with corresponding visibilities are given in Table (1).

Table (1)

Atmospheric attenuation in (dB/km) as a function of visibilities for 650 nm, 785 nm and 1550 nm.

Climate	***Visibility (km)***			***Attenuation (dB/km)***		
	650 nm [11]	***785 nm [8]***	***1550 nm [8]***	***650 nm [11]***	***785 nm [8]***	***1550 nm [8]***
Clear	20	23	23	0.7	0.5	0.2
Haze	2	2	2	7.77	7	4
Thin Fog	1.5	0.5	0.5	10.5	29	21
Light Fog	1	0.2	0.2	15.96	75	60
Heavy Fog	0.5	0.05	0.05	34.69	315	272

A low power red and infrared laser were employed with parameters with parameters given in Table (2) together with other parameters supposed in this simulation.

Table (2)
System parameters which used in this simulation.

parameter	*Value*		
	650 nm	***785 nm***	***1550 nm***
Transmitter optical power (mw)	5	20	70
Transmitter divergence angle (mrad)	1	1.5	3
Transmitter efficiency	0.5	0.5	0.5
Receiver sensitivity (dBm)	–20	–20	–20
Receiver diameter (cm)	10	10	10
Receiver efficiency	0.5	0.5	0.5

Therefore received optical power versus link range for (650, 785, 1550) nm is shown in Figs. (2, 3, 4), these calculation analyzed using eq.(6).

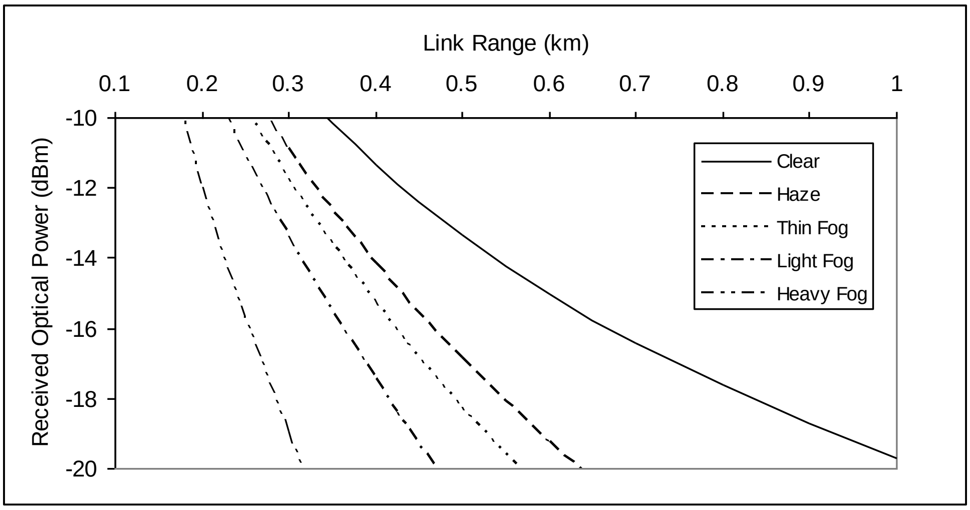


Fig. (2) Received optical power versus link range for 650 nm.

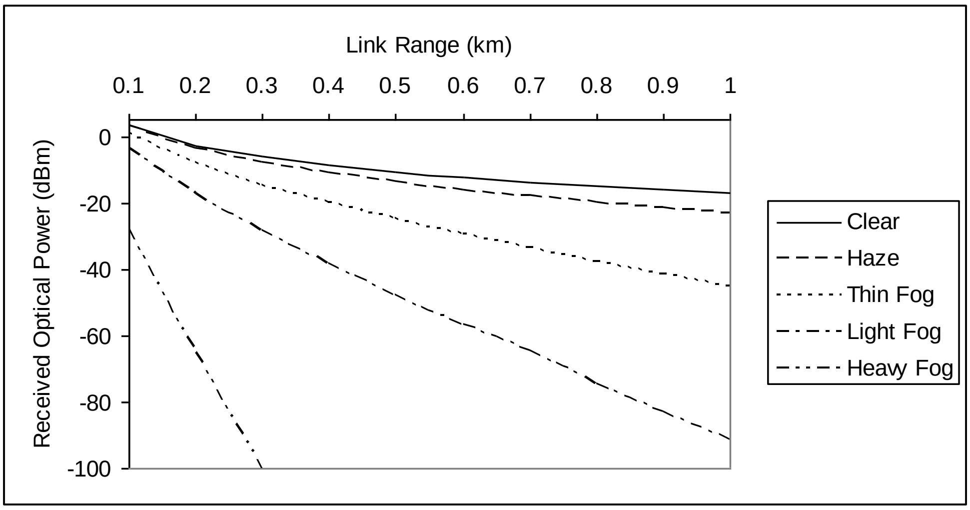


Fig. (3) Received optical power versus link range for 785 nm.

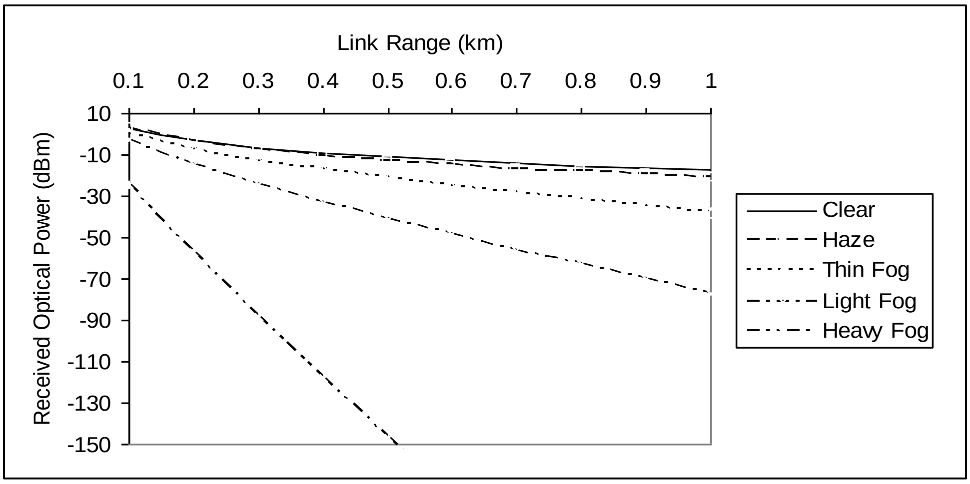


Fig. (4) Received optical power versus link range for 1550 nm.

The link margin value shows how much margin a system has at a given range to compensate for scattering, absorption and scintillation losses. Figs.(5, 6, 7) shows available link margin versus link range for the system (parameters given in Table (2)) and eq. (7) to achieve a given data rate 100 Mb/s operating under typical weather conditions. As seen in this figure, 13 dB of link margin is available for the proposed data link of less than 300 m for 650 nm.

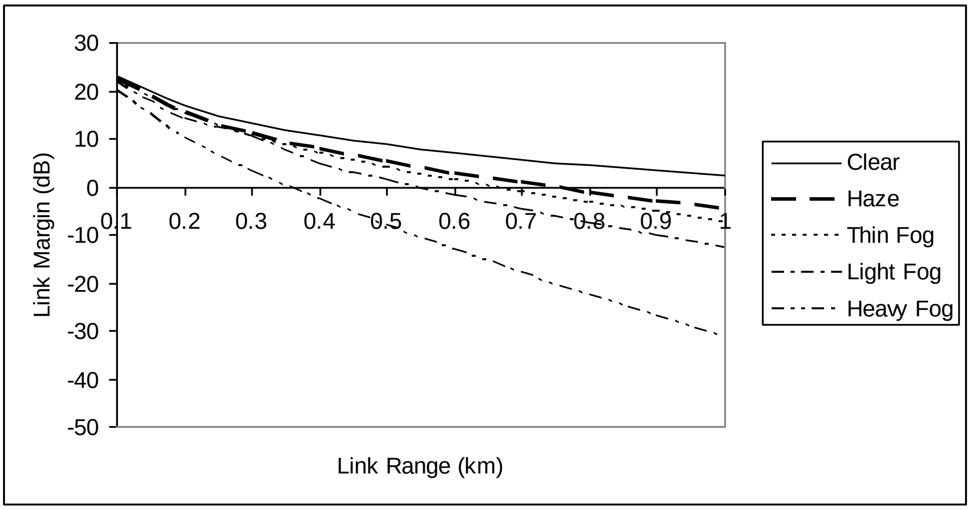


Fig. (5) Link margin versus link range for 650 nm.

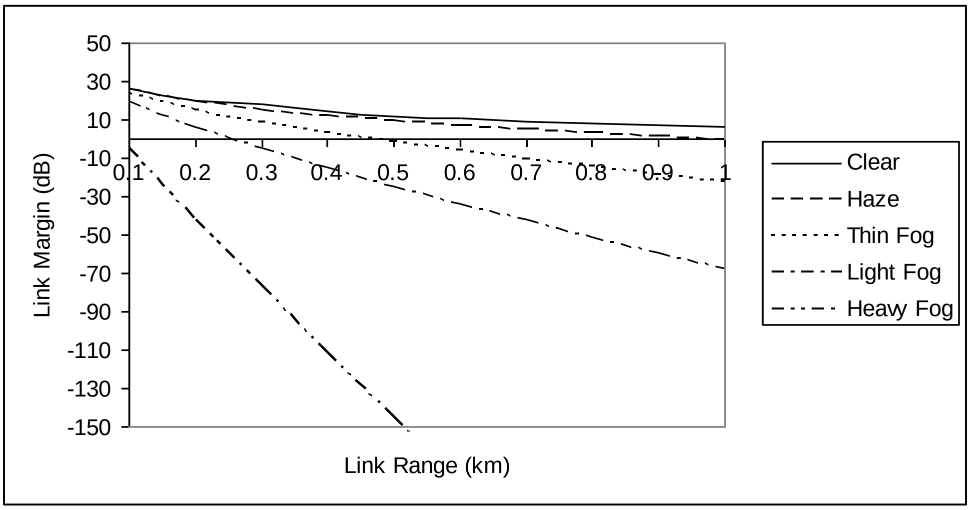


Fig. (6) Link margin versus link range for 785 nm.

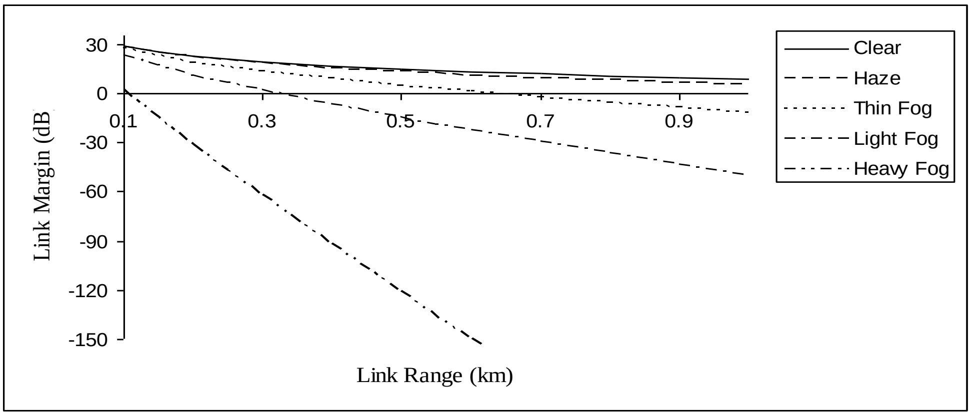


***Fig. (7) Link margin versus link range for 1550 nm*.**

The range equation can be used to generate the communications data rate versus range for varying atmospheric conditions [14]. So that we use a 650, 785 1550 nm, based on these assumptions data rate were calculates for signal attenuation due to weather events such as clear, haze, thin fog, light fog and heavy fog, data rate and link range applied in eq. (8) is shown in Figs.(8, 9, 10), increased data rate impossible if a higher power laser, or a larger aperture, or both, is used.

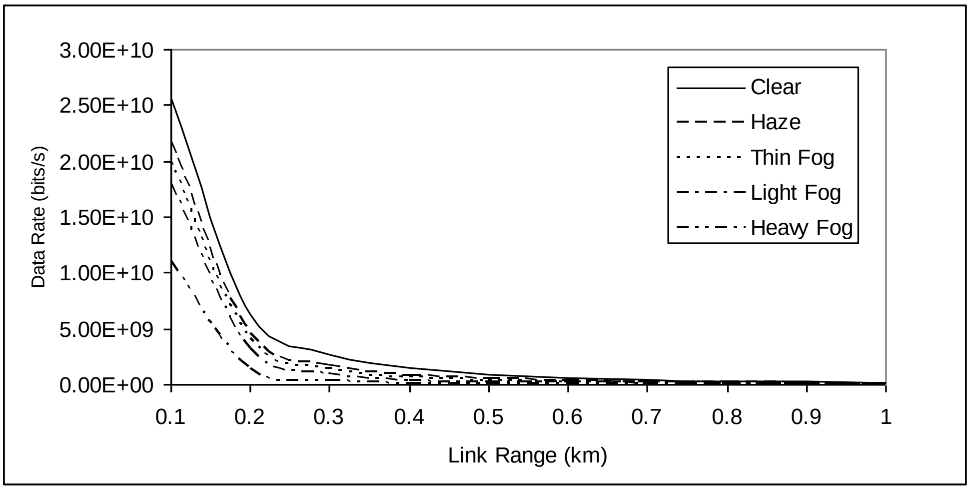


Fig. (8) Data rate versus link range for 650 nm.

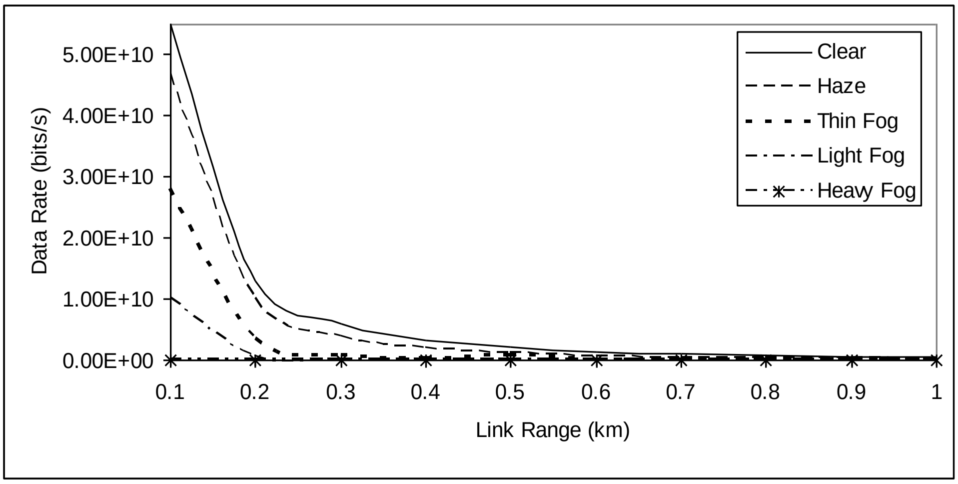


Fig. (9) Data rate versus link range for 785 nm.

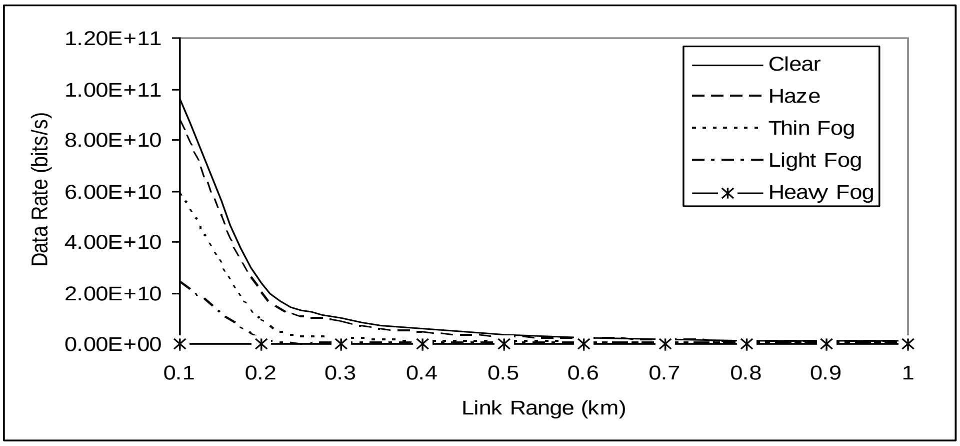


Fig. (10) Data rate versus link range for 1550 nm.

Conclusions

Atmospheric transmission of 650 nm, 785 nm, 1550 nm was analyzed theoretically. Performance parameters of a short range FSO system utilizing red and infrared was calculated. From this study the wavelength 1550 nm is less attenuated, more data rate and big receiver optical power comparison with (650, 785) nm. As a medium for short range FSO systems, red laser has both advantages and disadvantages when compared with infrared media. On the one hand, visible red laser sources capable of high-speed operation are available at low cost. Like the infrared, the visible spectral region is unregulated worldwide are not necessary. On the other hand, it is suitable only for short-range communications, as the output power of red laser is restricted due to eye safety problem. Red light laser can be modulated and used as signal light source in carrier space communications. Link performance can be optimized by varying system parameters such as transmitter optical power, transmitter beam divergence and receiver diameter, etc.

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الخلاصة

أجريت دراسة نظرية وتحليل تأثير بعض العوامل الجوية على ضوء الليزر كمصدر للاشارة الضوئية في الفضاء الحر ومناقشتها. تاثيرهذه العوامل على مقدار التوهين لاشعة الليزر حسبت عند الاطوال الموجية (٦٥٠، ٧٨٥، ١٥٥٠) نانومتر. ان قيم معامل التوهين كانت (٠,٦٩٨، ٠,٥٤٦، ٠,٢٢٥) dB/km الاطوال الموجية (٦٥٠، ٧٨٥، ١٥٥٠) نانومتر على التوالي عند المدى km ٢٠. وكذلك تم دراسة القدرة المستقبلة، سرعة نقل البيانات ومدى الارتباط عند تلك الاطوال الموجية تحت تأثير تلك الظروف المناخية. حيث تبين ان الظروف المناخية (clear, haze, thin fog, light fog, heavy fog) تؤثر على تلك الاطوال الموجية وبطرق مختلفة. فمن الممكن تحسين اداء النظام مثل مدى الارتباط وسرعة نقل البيانات عن طريق زيادة القدرة المرسلة وتقليل انفراجية اشعة الليزر.